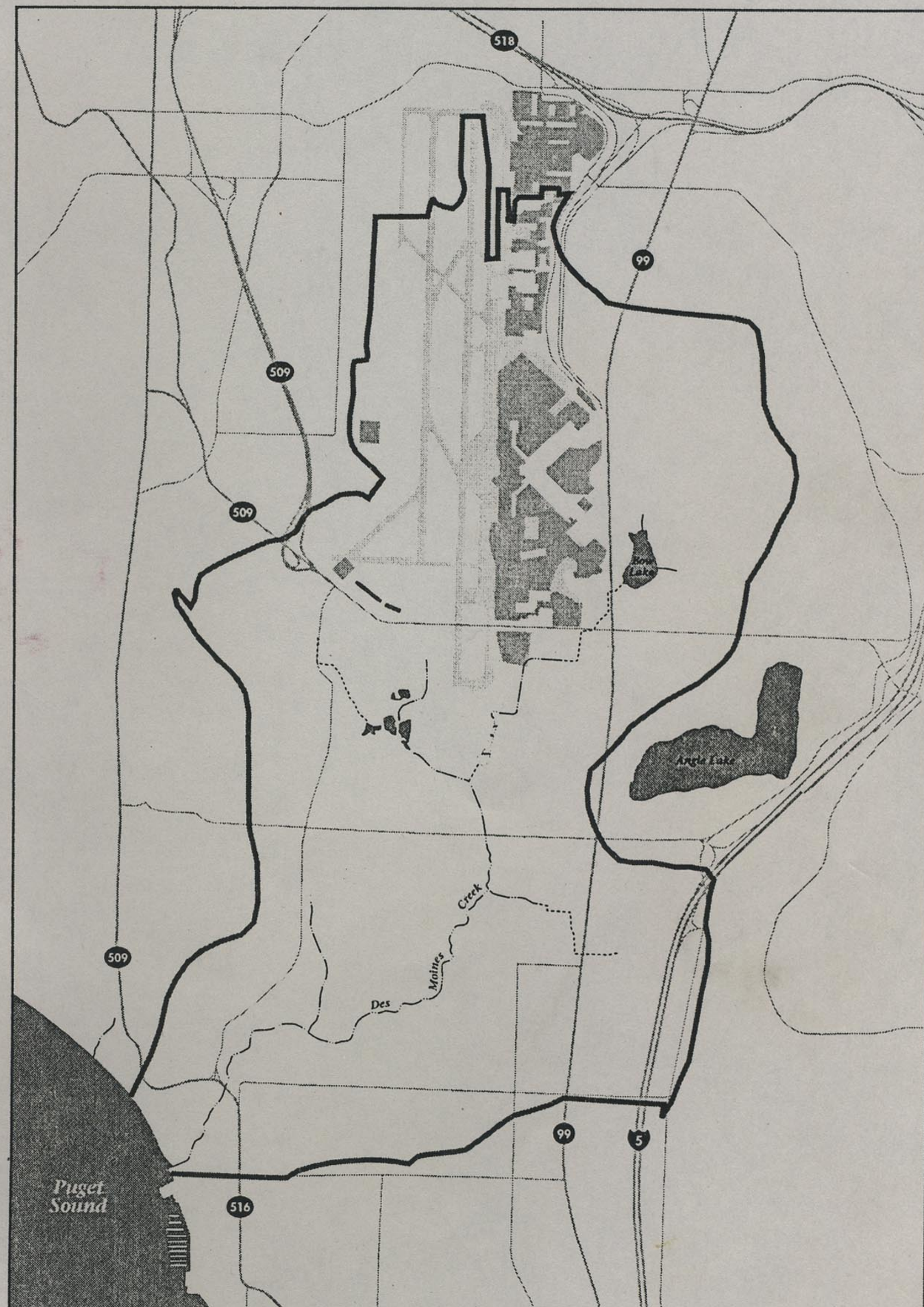
1997

Des Moines Creek Basin Plan



KING COUNTY

CITY OF DES MOINES
Sails With Pride

CITY OF SEATAC

Port of Seattle

DES MOINES CREEK BASIN PLAN

November 1997

Des Moines Creek Basin Committee

City of SeaTac
City of Des Moines
Port of Seattle
King County

Participants

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EXECUTIVE SUMMARY

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Des Moines Creek Basin Plan

EXECUTIVE SUMMARY

Background: The Des Moines Creek Basin Plan is the result of a cooperative, consensus-building effort initially undertaken by the Cities of SeaTac and Des Moines, and the Port of Seattle. Early discussions among the parties generated agreement that a basin plan for Des Moines Creek would assist in guiding infrastructure investments and in addressing the growing number of cross-boundary stream-related issues. These parties also agreed that the cooperative efforts would be better for the stream, improve opportunities for acquiring grants, and less expensive than if each of the jurisdictions performed stream work independently. The Cities and the Port then requested that the King County Department of Natural Resources Water and Land Resources Division (formerly Surface Water Management [SWM] Division) develop a scope of work and interlocal agreement to develop the basin plan. The jurisdictions subsequently requested the Water and Land Division carry out the scope of work for this project.

The primary goals of this Basin Plan are:

- to develop a flexible and resilient forum for addressing interjurisdictional stream issues;
- to develop a shared plan for addressing water quality and quantity issues;
- to develop prioritized Capital Improvement Projects (CIP) recommendations;
- to facilitate cooperative funding for interjurisdictional projects;
- to improve the quality of human interactions with the creek.

The Basin: The Des Moines Creek watershed covers 5.8 square miles of urban area near the center of the Seattle-Tacoma metropolitan region (see Figure 1.1 in Section 1). Des Moines Creek itself is approximately 3.5 miles long and flows from an elevation of about 350 feet to where it meets Puget Sound at Des Moines Creek Beach Park. The creek originates on a low gradient plateau and descends steeply through a ravine shortly before it empties into Puget Sound.

Most of the upper watershed is heavily urbanized, and includes residential and commercial land uses in the City of SeaTac and the Sea-Tac International Airport. Stream patterns in this upper watershed have been greatly altered from pre-development conditions and are now almost exclusively confined to culverts, road side ditches and drainage piping typical of urban areas. Upstream of Bow Lake on the East Fork, and upstream of Northwest Ponds on the West Fork, there is little evidence of a stream system at all.

Sea-Tac International Airport sits astride the drainage boundary between the East and West Forks and contributes flows to both. The airport has a complex surface water management system consisting of both an Industrial Wastewater System (IWS) and direct discharges to the stream system. Large portions of the airport consist of open grassy areas and other land uses which contribute little pollutant loading to the creek. These open grassy areas, and other areas of the airport facility that produce relatively small pollutant loading, are drained by a system of pipes that discharges directly to the stream system in a number of locations along the perimeter of the airport.

Drainage from areas of the airport that are more likely to contribute pollutants, such as aircraft servicing and loading areas, is collected and routed by the IWS to a water quality treatment plant located at the southwest corner of the airport complex. Water collected by the IWS is routed to one of three holding ponds before being processed by the wastewater treatment facility. Effluent from the IWS is routed by pipeline along Des Moines Creek to just below the Midway Sewage Treatment Plant where the IWS line joins the sewer outfall. The combined outfall line discharges to Puget Sound near the mouth of Des Moines Creek, approximately 1,700 feet off-shore at a depth of 170 feet.

Des Moines Creek has two major tributaries, two minor tributaries, and numerous small seeps and springs which surface within the ravine (see Figure 1.2 in Section 1 for water features and locations by River Mile). The two major tributaries, known informally as the East Fork and the West Fork, converge at River Mile (RM) 2.35 on the Tyee Golf Course at the south end of the airport. The confluence is approximately one-half mile upstream from the head of the ravine. The East Fork flows out of Bow Lake and for the first half mile it runs through a series of subsurface pipes, before surfacing at approximately 26th Avenue South. The West Fork flows out of the Northwest Ponds complex located at the western edge of the Tyee Golf Course.

Des Moines Creek and the two major tributaries begin providing limited fish and wildlife habitat once they reach the surface in the vicinity of the Tyee Golf Course. Upstream of the confluence (RM 2.35) there is some use of the creek by resident cutthroat trout although water quality problems limit use, particularly during summer months. In the West Fork, dissolved oxygen concentrations are far below the standard throughout the entire year and water temperatures are very high during much of the summer period. These conditions, stressful to fish, are due to natural conditions in the Northwest Ponds and channel conditions between Northwest Ponds and the confluence. Similar conditions in Bow Lake, particularly with regard to temperature, contribute to similar water quality problems in the upper part of the East Fork. The East Fork is also confined to underground pipes for much of the reach between Bow Lake and the Tyee Golf Course. Such conditions make it unlikely that these reaches are used by fish during the summer. Downstream of the confluence, conditions improve as the creek picks up additional gradient, additional water enters the stream, water quality problems such as elevated temperatures and decreased dissolved oxygen levels improve, and the riparian vegetation becomes denser. Cutthroat trout in this reach are larger and more numerous, and wildlife such as muskrat are occasionally seen.

Downstream of South 200th Street, the creek passes through a large wetland with a well-developed riparian zone before entering the head of a ravine at RM 1.85. From South 200th Street to its mouth at Puget Sound, Des Moines Creek is paralleled by a service road that contains the Midway Sewer District trunk line and the airport IWS discharge line. Distance between the service road and the Creek varies, with the road forming the stream bank in some locations.

The ravine, which runs for about three quarters of a mile from the wetland to the Midway Treatment Plant at RM 1.1, is a high-gradient reach with degraded habitat. This reach of the creek has been affected by increased flows due to urbanization and the stream bed has been scoured of most of its natural gravel, leaving a predominantly clay bed of minimal value to fish. Compounding the loss of natural gravel, the elevated flows have also eliminated many of the naturally occurring pools in this reach which would provide refuge for fish during high stream flows. Below the ravine, the creek passes by the Midway Treatment Plant where it is contained in a constructed channel with aging fish passage facilities. Below the Treatment Plant the ravine widens out and the creek develops a flood plain which allows a more meandering channel and well-developed riparian vegetation.

Separating the treatment plant reach from Des Moines Beach Park is a 225-foot-long box culvert that conveys the creek under Marine View Drive (RM 0.4). This culvert is a major impediment to migrating salmon and trout, and it produces potentially unsafe conditions by ponding flood water behind the road fill during major storm events. Although the Marine View Drive culvert limits flows during major storm events, it does not prevent flooding of buildings located in the park. In effect, the culvert reduces the magnitude of large events (greater than 5-year events) but does not change their frequency.

The creek in Beach Park currently provides some of the most heavily utilized fish habitat of the system, due primarily to its accessibility to fish returning from the sea. Coho and chum salmon, steelhead, and cutthroat trout have all been identified recently in the lower reaches of Des Moines Creek and spawning activity has been observed. Two existing buildings in this reach, which the City of Des Moines is considering removing, are built directly over the stream and are subject to frequent flood damage. Previous flooding problems caused by the access bridge in the Park have been greatly reduced with the replacement of the bridge by the City of Des Moines in 1996.

Fish and Wildlife: Fish are still found throughout the stream system in small to moderate numbers. Resident and searun cutthroat trout, coho salmon, steelhead, and possibly pink salmon have all been observed recently in Des Moines Creek. Pumpkinseed sunfish and largemouth bass, both introduced species thought to be coming from Bow Lake and Northwest Ponds, also are found occasionally throughout the upper system.

Fish production within Des Moines Creek is currently limited by a number of factors. Barriers to fish passage severely limit the ability of anadromous salmonids (searun cutthroat, coho, steelhead, and pinks) to reach potential spawning areas above Marine View Drive. High stream flows and resulting erosion and sedimentation have caused the loss of many naturally occurring pools, serving to limit rearing and overwintering habitat and reduce the number of fry that successfully migrate out to salt water. Low stream flow levels in summer further limit the amount of rearing habitat available. Water quality problems such as elevated water temperatures and, in some reaches, lowered levels of dissolved oxygen stress fish and further reduce successful rearing, particularly among the native salmonids.

Wildlife is still relatively common along the stream corridor. Red fox, raccoon, and muskrat have been observed over the last several field seasons. Bald eagles, herons, and kingfishers have also been seen regularly and suggest that a reasonably healthy fish population still exists.

Water Quality: Des Moines Creek has several water quality problems, although none are immediately threatening to the existing fish population. The creek is listed as an impaired water by the State due to consistently high fecal coliform levels. Investigations undertaken during preparation of this Basin Plan indicate that most of this fecal contamination is the result of human waste disposal activities, primarily poorly functioning septic systems. Elevated fecal coliform levels may present a health risk to humans who come into contact with stream water, but do not present a problem for aquatic organisms such as fish.

Water quality does present a problem for fish utilization above the confluence of the East and West Tributaries on the Tyee Golf Course. Low dissolved oxygen levels and elevated temperatures render portions of these tributaries unusable to fish during some summer periods. Fortunately, mixing of the two tributaries and aeration from the three weirs on the golf course below the confluence returns dissolved oxygen to near-normal levels by the time the creek reaches South 20th Street. Other water quality issues are similar to those of urban areas throughout Puget Sound and result from numerous non-point sources of pollution.

Past Changes: Human activity within the Des Moines Creek watershed has resulted in the removal of most of the native forest and the creation of substantial impervious areas, such as roads, parking lots and buildings. Impervious areas do not allow rain water to infiltrate into the ground and the water runs off rapidly, creating higher stream flows during storms with resulting erosion and habitat degradation. Since less water can infiltrate, the ground water supply is reduced which then results in lower stream flows during the summer. Approximately 35 percent of the basin is currently covered with impervious surfaces that drain to the stream system, well above the 10 percent impervious area threshold at which streams in this region typically start to show obvious signs of serious degradation.

Land use changes in the basin have resulted in major changes to the stream. The increased impervious area has resulted in increased peak flows, with peak annual flows in both the main tributaries and the mainstem averaging more than four times greater than they were prior to development of the basin. Erosive flows, capable of scouring channels and moving bed sediments occur more than 20 times as often. Floods of a magnitude that used to occur, on average, every 100 years now occur every two years on average.

Future Changes: Urban development in the basin at buildout is expected to increase the amount of impervious area that drains to the creek within the basin from the current 35 percent to over 47percent. Most of this increase will result from development within the cities. The remainder will be split equally between the three big projects currently proposed within the basin. These projects are the State Route 509 extension, the South Aviation Support Area (SASA), and the 3rd Runway Expansion.

With no response by the jurisdictions, these land use changes will further increase the stream's ability to cause erosion by approximately 70 to 100 percent, resulting in increased channel erosion and habitat degradation. Water quality is also expected to undergo similar changes, with an overall degradation basin wide. Water quality will be degraded the most in the sub-basins anticipating the highest level of land use change.

Possible Responses: The most practical tools available to minimize the future impacts of this increased impervious area are limited to detention ponds (which store water), bypass pipes (which route water around the sensitive channel portions), and changes to regulations governing the amount of development allowed and the extent of mitigation required of new development. Other tools for addressing impacts from changes in impervious area such as infiltration, changes in zoning, and other detention methods like underground vaults were judged to be impractical in this basin. A variety of pond sizes and combinations of different tools were investigated to determine how effective they would be in improving stream conditions, and what their cost would be.

Possible alternatives were grouped into three levels of effectiveness: those that did not significantly slow the current rate of degradation; those that slowed the rate of degradation but did not stop it; and those that either halted degradation or allowed improved stream conditions. Cost estimates for these different combinations showed that each cost approximately the same due to the ability of the more effective alternatives to reuse existing infrastructure such as the soon-to-be-abandoned Midway Sewer District sewer pipe. Although one option (small bypass only) was identified that was substantially cheaper, this option did little to slow the rate of degradation facing the stream and was judged to be of little benefit in meeting the goals of the project. The interjurisdictional project management team decided to further investigate only those alternatives which halted degradation or improved conditions.

Alternatives: Three alternatives were identified that could potentially improve, and at a minimum, stop degradation of stream conditions due to current and anticipated future peak flows. The first alternative involves construction of a large in-stream detention pond complex in the vicinity of the Tyee Golf Course, use of Bow Lake for additional detention, and increasing detention requirements in drainage regulations for new development throughout the basin. The second alternative involves construction of a large bypass pipe from the vicinity of the golf course down to Puget Sound. The third alternative involves construction of an in-stream detention pond in the vicinity of the golf course combined with the use of an existing abandoned sewer pipe as a small bypass pipe.

Recommendations: The Des Moines Creek Basin Committee recommendation for peak flow control is to pursue the third alternative (the combined bypass and detention pond) because it is extremely effective, is the least costly, can be performed in three phases if desired, and minimizes potential design and permitting difficulties. The recommended peak flow control facility, a combined bypass and detention pond, is estimated to cost approximately $5.2 M. A well and pump system to supply additional water to the stream is also recommended for construction near South 200th Street to address dry season water quality concerns including low flow, elevated temperatures, and potential low dissolved oxygen levels. The flow augmentation facility is estimated to cost approximately $65,000. A series of aquatic habitat improvement projects are also recommended to improve fish habitat throughout the basin, with habitat enhancement projects concentrated in the lower reaches and habitat stabilization work occurring in the ravine. No anadromous fish use is proposed above South 200th Street. Habitat improvements in this area are focused on improving water quality and minimizing bird use (in response to air traffic safety concerns). Habitat improvement work is estimated to cost $260,000.

Several recommendations do not involve construction. The most important of these is to keep the Des Moines Creek Basin Committee active. The basin committee will need to keep meeting regularly during the design and construction phase of the capital projects to resolve design and construction issues, to respond to permitting issues, to respond to public inquiries, to seek grant funding for projects, and to assist in development of appropriate mitigation strategies for large projects such as the State Route 509 extension. The basin committee will also be called upon to assist in resolving unforeseen stream related issues, and to coordinate efforts with agencies on projects in the basin such as the Midway Sewer District, and the Marine View Drive culvert replacement effort. To be effective and to respond in a timely fashion, the basin committee will need some level of dedicated staff effort during the implementation phase. Once the CIP program has been implemented, it is anticipated that most other staffing needs can be covered by existing city and Port staff.

Other non-project recommendations include joint funding and management of the recommended basin CIP projects, continued and expanded involvement of other parties in the basin, expansion of water quality improvement efforts with business and educational institutions, improved utilization of volunteer efforts to improve stream habitat conditions, and revision of existing spill response plans to more effectively utilize the anticipated improvements to the drainage system.

The listing of Des Moines Creek as an impaired water by the State and the identification of humans as the principal source of the fecal contamination creates the need for an effective response. A program to identify existing septic systems in the watershed should be initiated. Once identified, a survey should be performed to identify the effectiveness of existing septic systems in treating human waste. Finally, a program to correct existing problems through a combination of education, maintenance, replacement and connection to sewers should be initiated.

Summary of Basin Plan Recommendations

	Problem Addressed	Cost
CIP Recommendations		
Construct combined Detention/Bypass Project	High flows, erosion, water quality.	$2,200,000 in Phase 1; $5,200,000 total
Support replacement of Marine View Drive culvert	Blockage of fish passage.	Basin Committee share appros. $2,000,000. Total project cost estimated at $4,000,000
Outlet improvements to Bow Lake	High flows, erosion, water quality.	$80,000.
Construct Low Flow Augmentation Facility	Low flows, high temperatures and low dissolved oxygen levels.	$65,000 construction.
Habitat Recommendations		
Riparian Habitat Improvements	Poor habitat conditions.	Total $260,000 for Phase I; $750,000 total
In-stream Habitat Improvements	Poor habitat conditions.	Included in riparian habitat estimate.
Water Quality Recommendations		
Reduce Fecal Coliform bacteria	Contamination of creek from human sewage or septage.	$50,000. Work with state and local Health departments to identify and control sources.
Improve management of roadway runoff	Metals and petroleum in runoff.	Not estimated. Work with WSDOT and local jurisdictions.
Continue to identify point sources and implement source control BMPs.	Non-point source pollution.	Not estimated. Work with WDOE and local jurisdictions.
Public involvement and outreach	Inappropriate actions by citizens.	Not estimated. Work with Puget Sound Watershed Forum, Puget Sound Action Team and local jurisdictions.
Reduce impervious area	Decrease rate of problem growth.	Not estimated. Individual jurisdictions.
Programmatic Recommendations		
Continue Basin Committee process	Provide forum for interjurisdictional communication and problem solving.	Not estimated.
Joint funding and management of projects	Continue cooperative interjurisdictional effort.	Not estimated. Part of Basin Committee effort.
Develop a monitoring program	Ascertain improvements are working, trigger subsequent phases.	Not estimated. Include as part of CIP costs.
Continue involving outside parties	Improve implementation.	Not estimated. Part of Basin Committee effort.
Start programmatic effort	Long term water quality improvements.	Not estimated. Part of Basin Committee effort.
Revise spill response plan	Prepare to respond to non-airport related spills.	Not estimated. Work with WSDOT, emergency management and local jurisdictions.

1. INTRODUCTION

1.1. Overview

The Des Moines Creek Basin Plan is the result of a cooperative interjurisdictional effort funded by the jurisdictions of SeaTac, Des Moines, the Port of Seattle, and King County for the purpose of identifying and addressing surface water issues in the Des Moines Creek basin. The primary goals of this interjurisdictional effort are to develop a shared plan for addressing water quality and quantity issues, to develop prioritized Capital Improvement Projects (CIP) recommendations, to facilitate cooperative funding for interjurisdictional projects, to improve the quality of human interactions with the creek, and to develop a flexible and resilient forum for addressing stream issues.

In early 1995 the City of SeaTac, City of Des Moines, and the Port of Seattle formed the Des Moines Creek Basin Committee. The Basin Committee began meeting to define the goals and objectives of a watershed-based planning effort and to address increasingly obvious problems facing the Des Moines Creek basin. After several months of preliminary discussions these jurisdictions requested the participation of the Water and Land Resources (WLR) Division (formerly the Surface Water Management [SWM] Division) of the King County Department of Natural Resources to assist the basin committee with development of a Scope of Work (SOW) and an Interlocal Agreement (ILA) for preparing the Des Moines Creek basin plan. Upon completing the SOW and ILA, the WLR Division was requested to continue providing technical assistance and project management on behalf of the Des Moines Creek Basin Committee.

1.2. Description of the Basin

The Des Moines Creek basin covers 5.8 square miles of urban area near the center of the Seattle-Tacoma metropolitan area. Des Moines Creek itself is approximately 3.5 miles long and falls from an elevation about 350 feet to where it meets Puget Sound at Des Moines Creek Beach Park. As is common throughout Puget Sound urban area, the creek originates on a plateau and has a fairly low gradient until it descends steeply through a ravine shortly before it empties into Puget Sound. Figure 1.1 shows the location of the watershed and its relationship to the jurisdictions in the area.

Des Moines Creek has two major tributaries, two minor tributaries, and numerous small seeps and springs which surface within the ravine. There are also two major water bodies within the watershed, Bow Lake and the Northwest Ponds complex, which both lie within the City of SeaTac. Figure 1.2 shows the water features in the watershed and identifies locations along the stream by river mile (RM). Locations on the stream will be identified by river mile (RM) throughout this report. Please refer to Figure 1.2 for these locations.

The two major tributaries, known informally as the East Fork and the West Fork, converge on the Tyee Golf Course approximately one-half mile above the head of the ravine. The East Fork flows out of Bow Lake, for the first half mile through a series of subsurface pipes, to where it surfaces at approximately 26th Avenue South. The West Fork flows out of the Northwest Ponds complex located at the western edge of the Tyee Golf Course.

Most of the upper watershed is heavily urbanized, with residential and commercial land uses in the City of SeaTac, and includes the Sea-Tac International Airport. Surface water runoff in this upper watershed has been greatly altered from pre-development conditions and is almost exclusively confined to culverts, roadside ditches, and drainage piping typical of urban areas.

Seattle-Tacoma (Sea-Tac) International Airport sits astride the drainage boundary between the East and West Forks and contributes runoff flows to both tributaries. The airport has a complex surface water management system consisting of both an Industrial Wastewater System (IWS) and direct discharges to the stream system. Large portions of the airport consist of open grassy areas and other land uses that contribute little pollutant loading to the creek. These open grassy areas, and other areas of the airport facility that produce relatively small pollutant loading, are drained by a constructed system of pipes similar to an urban area drainage system. This drainage system discharges directly to the stream system in a number of locations located along the perimeter of the airport.

Drainage from areas of the airport that are more likely to contribute pollutants, such as aircraft servicing and loading areas, is collected and routed by the IWS to a water quality treatment plant located at the southwest corner of the airport complex. Water collected by the IWS is routed to one of three holding ponds before being processed by the wastewater treatment facility. Effluent from the IWS is routed by pipeline along Des Moines Creek to just below the Midway Sewage Treatment Plant where the IWS line joins the sewer outfall. The combined outfall line discharges to Puget Sound near the mouth of Des Moines Creek, approximately 1800 feet off-shore at a depth of 180 feet.

Des Moines Creek and the two major tributaries begin providing limited fish and wildlife habitat once they reach the surface in the vicinity of the Tyee Golf Course. Upstream of the confluence (RM 2.35 - see Figure 1.2 for location by river mile) there is some use of the creek by resident cutthroat trout, although water quality problems limit use, particularly during summer months. In the West Fork, dissolved oxygen concentrations are far below the standard throughout the entire year and water temperatures are very high during much of the summer period. these conditions, stressful to fish, are due to natural conditions in the Northwest Ponds and channel conditions between Northwest Ponds and the confluence. Similar conditions in Bow Lake, particularly with regard to temperature, contribute to similar water quality problems in the upper part of the East Fork. The East Fork is also confined to underground pipes for much of the reach between Bow Lake and the Tyee Golf Course. These conditions make it unlikely that these reaches are used by fish during the summer. Downstream of the confluence, conditions improve as the creek picks up additional gradient, additional water enters the stream, water quality problems such as elevated temperatures and decreased dissolved oxygen levels improve, and the riparian vegetation becomes denser. Cutthroat trout in this reach are larger and more numerous, and wildlife such as muskrat are occasionally seen.

Downstream of South 200th Street, the creek passes through a large wetland with a well-developed riparian zone before entering the head of a ravine at RM 1.85. From South 200th Street to its mouth at Puget Sound, Des Moines Creek is paralleled by a service road that contains the Midway Sewer District trunk line and the airport Industrial Wastewater System discharge line. Distance between the service road and the creek varies, with the road forming the stream bank in some locations.

The ravine, which runs for about one-half mile from the wetland to the Midway Treatment Plant at RM 1.1, is a high-gradient reach with degraded habitat. This reach of the creek has been affected by increased flows due to urbanization and the stream bed has been scoured of most of its natural gravel, leaving a predominantly clay bed of minimal value to fish. Compounding the loss of natural gravel, the elevated flows have also eliminated many of the naturally occurring pools in this reach which would provide refuge for fish during high stream flows. Below the ravine, the creek passes by the Midway Treatment Plant where it is contained in a constructed channel with fish passage facilities that are aging. Below the Treatment Plant the ravine widens out and the creek develops a flood plain which allows a more meandering channel and well-developed riparian vegetation.

Separating the treatment plant reach from the Des Moines Beach Park is a 225 foot-long box culvert that conveys the creek under Marine View Drive (RM 0.4). This culvert is a major impediment to migrating salmon and trout, and it produces potentially unsafe conditions by ponding flood water behind the road fill during major storm events. Although the Marine View Drive culvert limits flows during major storm events, it does not prevent flooding of buildings located in the park. In effect, the culvert reduces the magnitude of large events (greater than 5-year events) but does not change their frequency

The creek in the Beach Park currently provides some of the most heavily utilized fish habitat of the system, due primarily to its accessibility to fish returning from the sea. Coho and chum salmon, steelhead, and cutthroat trout have all been identified recently in the lower reaches of Des Moines Creek and spawning activity has been observed. Two existing buildings in this reach, which the City of Des Moines is considering removing, are built directly over the stream and are subject to frequent flood damage. Previous flooding problems caused by the access bridge in the Park have been greatly reduced with the replacement of the bridge by the City of Des Moines in 1996.

1.3. Des Moines Creek Basin Committee

The Des Moines Creek Basin Committee is composed of representatives of Des Moines, SeaTac, the Port of Seattle and King County. The Basin Committee is an interjurisdictional forum focused on addressing surface water and water quality issues in Des Moines Creek and meets monthly. In addition to providing a forum for interjurisdictional coordination, the Basin Committee serves as the project management team for the ongoing basin planning effort. The Basin Committee provides policy level guidance to the technical team, as well as serving as the decision-making body for issues of scope and budget. Although the Basin Committee has a formal decision-making process involving voting, the Committee has, to date, been entirely a consensus driven decision-making body.

1.4. Surface Water Management Technical Team

The basin planning technical team is an interdisciplinary team composed of highly experienced basin planning specialists, primarily employed by King County WLR Division. Specialties represented on the planning team include engineering, ecology, hydrology, geology, water quality, land use planning, and project management. The role of the technical team was to examine existing conditions and information; identify and prioritized problems in the basin; develop new information where crucial data was missing; analyze the existing and projected future condition of the creek; and develop specific recommendations for improving the overall ecological health of the stream system.

The technical team works entirely at the direction of the Basin Committee. Analysis and recommendations developed by the technical team are forwarded to the Basin Committee for review and approval on a regular basis before distribution or inclusion in reports.

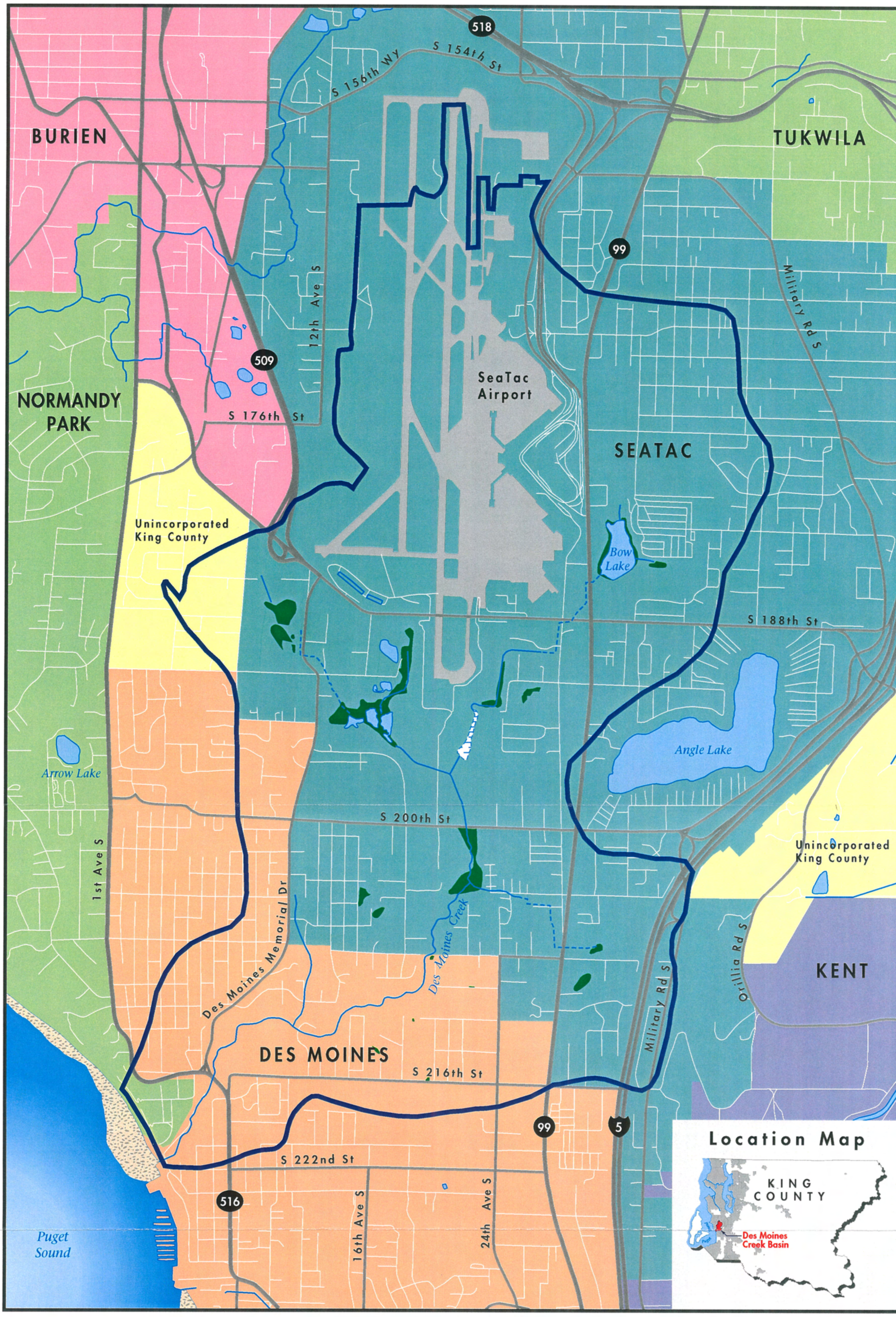

Figure 1-1

DES MOINES CREEK BASIN
Jurisdictions

Basin Boundary
Stream
Piped Stream
Lake
Wetland
R/D Facility

N

0 — 1/2 Mile

October 1997

Map produced by:
DNR GIS/Cartography/
Graphics Unit

Base Map Notes:
All updates register to USGS PLS
Wetland Sources:
Port of Seattle Wetland Mapping, 1995
Map does not include wetland #22
Stream and Pipe Location Sources:
USGS Digital Line Graph
King County Basin Recon Program, 1987
Aerial Photos, 1989
Port of Seattle Field Mapping, 1995
Roadway Sources:
USGS Digital Line Graph
Aerial Photos, 1989
Industrial Wastewater System Source:
Port of Seattle Comprehensive Stormwater and Industrial Wastewater Plan
Contour Lines Source:
USGS Digital Elevation Model
Incorporated Areas Source:
King County GIS coverage

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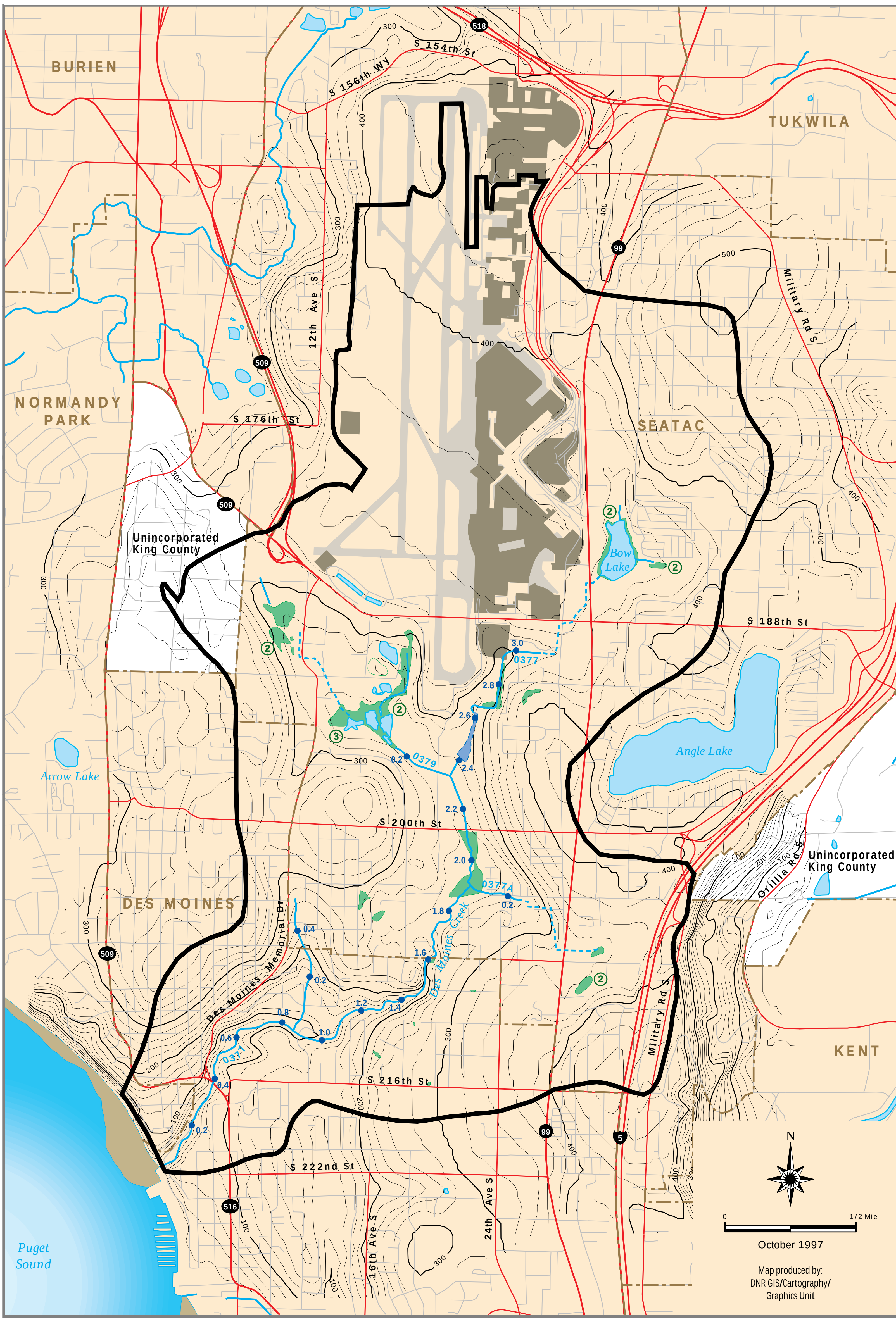

Figure 1-2

DES MOINES CREEK BASIN

Water Features

- Basin Boundary
- Stream
- Piped Stream
- 0377 Stream Number
- 2.6 River Mile
- 20-foot Contour
- Incorporated Area
- Industrial Wastewater System
- Lake
- R/D Facility
- Wetland
- Wetland Rating (where available)

Base Map Notes:
All updates register to USGS PLS
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Contour Lines Source:
USGS Digital Elevation Model
Incorporated Areas Source:
King County GIS coverage

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2. BACKGROUND ON DES MOINES CREEK

2.1. Historical Discussion

2.1.1. Natural History

The history of the Des Moines Creek basin and its surroundings is well documented (Eyler and Yeager 1972; Draper 1975; Kennedy and Schmidt 1989). Both the Duwamish and Muckleshoot tribes used the area prior to European settlement and continued to do so for many years after. The Duwamish arrived by canoe while the Muckleshoots came overland from the Green River. Indians camped on all the beaches from Three Tree Point to Commencement Bay to dig clams and spear the salmon ascending the many creeks, including Des Moines Creek (Eyler and Yeager 1972; Draper 1975; Kennedy and Schmidt 1989).

Although the first homesteader arrived by boat in 1867, settlement in and around the present city of Des Moines did not commence until 1882. Because the basin was heavily forested, logging and sawmills were the first principal industries with both fixed-location and portable sawmills being used. One such operation, located near current location of the wastewater treatment plant, was powered by a water wheel with logs brought to it via a flume in Des Moines Creek. Logging continued in the area until 1925.

From the historical record, it is apparent that the Des Moines Creek basin was heavily forested with a stream that had abundant large wood in the channel to produce a complex array of habitat types. The principal natural disturbance regime was probably fire, as suggested by observations of the surveyors for the old military road in 1858 (cited in Kennedy and Schmidt 1989). Based on an old photograph in Eyler and Yeager (1972), the plateau area was replete with forested wetlands and bogs, particularly in the headwaters around Bow Lake, which is a peat-bog lake.

2.1.2. History of Fish Usage

On nearby Miller Creek, salmon ascended the stream to the vicinity of Sunnydale School (recollection of early resident Charlie Hughes, cited in Eyler and Yeager 1972). This school, located on 8th Avenue South at Southwest 156th Street, is approximately three river miles from the mouth. Williams et al. (1974) lists an impassable falls at this location. Given this observation, salmon could also have ascended at least as far up Des Moines Creek, perhaps to Bow Lake if no barriers were present. Williams et al. (1975) report an “impassable cascade” in Des Moines Creek at RM 1.5 (see Figure 1.2) that may or may not have been present in pioneer days. This location is currently within the ravine reach of the creek and is characterized by a streambed with little gravel and a lack of pools. While not impassable, the area is characterized by high water velocities and little useful fish habitat.

Des Moines Creek probably supported coho salmon (*Oncorhychus kisutch)*, chum salmon (*O. keta*), and searun cutthroat trout (*O. clarkii*) as the principal anadromous species. Steelhead (*O.* mykis) were undoubtedly present, but probably not in large numbers. While steelhead are not usually predominant in small basins like Des Moines, searun cutthroat trout are common (Hartman and Gill 1968). The Des Moines Creek searun cutthroat trout would probably have been the late-entry variety, which ascend small Puget Sound streams from late winter through early spring (Johnston 1981). While pink salmon were not listed as using Des Moines Creek (Williams et al. 1975), several have been seen by knowledgeable observers in the lower part of the creek in recent years.

Resident coastal cutthroat trout also likely existed in the basin, principally in the canyon and plateau reaches, and in Bow Lake. Peat-bog lakes such as Bow Lake can and frequently do support resident cutthroat trout (Shepherd 1974).

By the turn of the century, most lakes in the Puget Sound region had been stocked with warm water fish species. Bow Lake appears to have been no exception. Small pumpkinseed sunfish (*Lepomis gibbosus*) were the second-most common fish captured in the 1996 electrofishing inventory between Marine View Drive and South 200th Street (see Existing Conditions, 3.5 Fisheries). Largemouth bass (*Micropterus salmoides*) and sculpins (*Cottus sp.*) are also now present in the creek.

2.2. Summary of Previous Studies and Information

2.2.1. Stream Studies

Previous studies (King County 1974, 1987; Metro 1987, 1989) have established that the creek was severely degraded by urbanization. The problems identified by these studies included channel and bank erosion, degraded fisheries, and flooding in the Des Moines Beach Park.

The habitat in Des Moines Creek has been inventoried several times in recent years. In August, 1986, staff from the Municipality of Metropolitan Seattle and the Muckleshoot Tribe walked the entire reach of open stream channel (Metro 1987). The data from this inventory consisted of both qualitative and quantitative observations of the physical features of the stream.

The Metro (1987) inventory found little diversity or abundance of habitat in the first 0.4 mile of stream. The stream in this reach, which flowed through what was then essentially a “residential area,” had been extensively altered. It was confined by riprap on both banks and crossed numerous times by small foot bridges. The creek was mostly “natural” from RM 0.37 to RM 2.06 (see Figure 1.2). The stream was described has having “ abundant large woody debris...and a pool-riffle ratio of nearly one-to-one.” Upstream of RM 2.0 (approximately South 200th Street), the stream had been channelized and placed in a culvert through portions of the Tyee Golf Course. There was little instream habitat in this reach of the stream.

The stream was again inventoried in early December, 1993 (Minton 1994). This inventory found that although 15 habitat types were present; riffle habitat was most common, followed by shallow lateral scour pools. These habitats are “fast water” habitats, and as such provide only limited refuge areas during higher flows. This lack of refuge habitat was further demonstrated by the shallow residual pool depths. Of the 133 residual pools identified, more than half were less than one foot in depth. A residual pool depth of one foot or more is generally considered ideal for salmonids. This inventory also found a general lack of woody debris in Des Moines Creek. The number of pieces of woody debris was 25 to 40 percent of that typically found in old growth forest streams. While this is a surprisingly large percentage for an urbanized stream system, this is still well below optimal conditions for fish habitat.

The 1993 study also modeled the relationship between fish habitat and flow using the U.S. Fish and Wildlife Service's Physical Habitat Simulation system (PHABSIM). This investigation estimated that the maximum refuge habitat existed at approximately 20 cfs, then decreased rapidly with increasing flows. Most of the refuge habitat was provided by instream conditions (i.e., water depth and low water velocities); the limited available woody debris provided little additional habitat.

2.2.2. Water Quality Studies

The following paragraphs summarize water quality studies which have been done to date on Des Moines Creek. It is important to note that many of these studies draw conclusions based on very small numbers of water quality samples taken under highly variable conditions. These study summaries are included to document the evolution of water quality understanding in the Des Moines Creek basin and to indicate the level of knowledge from which this effort began.

Water Quality and Drainage Study

The first comprehensive study of water quality in the creek, "Water Quality and Drainage Study" (Stevens, Thompson and Runyan 1974), was conducted in 1973-74 for the Sea-Tac airport and master drainage planning program. Examination of the data (Minton, 1995) indicated several potential water quality issues. The stream had high fecal coliform concentrations during both storm and base flows, and it has since been listed by the Washington State Department of Ecology (WSDOE) as a stream failing to meet water quality standards for fecal coliform contamination. The source of this contamination is currently under investigation. Other water quality problems identified included high zinc concentrations during storms, frequently elevated levels of phosphorous and nitrate, and high temperatures during the summer. Sampling of invertebrates also shows a community composition that indicates disturbances in the stream.

Des Moines Creek Restoration Study

Between 1985 and 1986, two major spills of toxic jet fuel occurred, nearly eliminating all aquatic life along most of the stream (Beck, 1990). In 1986, Metro, King County, the Port of Seattle, the WSDOE, and Trout Unlimited began working together to restore Des Moines Creek. Based on those discussions, the Des Moines Creek Restoration Project (Herrera and Hall, 1989) presented a plan to control and maintain water quality in the creek and to restore salmon and trout populations. The Restoration Project identified problems and suggested solutions for rehabilitating the stream following the fuel spills.

In the restoration plan, numerous violations of WSDOE water quality standards for Class AA streams were reported for fecal coliform bacteria, metals, and turbidity (Herrera and Hall, 1989). Lead, copper, zinc, and turbidity concentrations were high during storm events, indicating surface runoff as a source of contamination (Herrera, 1995). High temperature and low dissolved oxygen were observed in summer months. Pesticides and herbicides including DDT, aldrin, dieldrin, 2,4-D, and 2,4,5-T were also detected instream at elevated concentrations (Herrera, 1995).

South Aviation Support Area Studies

In 1992, water quality information was needed to support the analysis of construction and mitigation alternatives for the South Aviation Support Area (SASA). An expansion of aircraft servicing facilities which would be located on the northeast portion of the Tyee Golf Course was proposed. Because the proposed alternatives included major modifications to upper Des Moines Creek and the basin, the Port conducted a study to characterize the pre-construction stormwater quality (Parametrix, 1992). The results of the study indicated that water quality standards for Class AA streams were not being met for fecal coliforms throughout the stream, and standards for pH and turbidity were violated at certain upper reaches of the creek. Chronic and acute criteria for copper and zinc were exceeded in the upper reaches of Des Moines Creek and in the parking lot adjacent to the tank farm located at approximately RM 3.0. Metal concentrations and rainbow trout bioassays generally indicated that toxic conditions were not present in lower Des Moines Creek downstream of South 200th Street. Tributaries entering the creek below South 200th Street were of higher quality than the creek, thus enhancing the water quality of the creek by diluting pollutant loads. Lastly, increases in nitrogen levels were thought to indicate fertilizer applied to the golf course enters the creek

Des Moines Creek Problem/Solution Assessment

In 1995, an informal summary of the problems in the mainstem of the creek and proposed solutions, as identified by previous studies, was prepared (Minton, 1995). In addition to the previously mentioned problems, the report mentions periphyton growth which appears excessive and which decreases in density from the upper basin downstream to the treatment plant. The report mentions that the apparent excessive growth is likely due to the runoff of fertilizers from the golf course.

This report also describes actions taken to date to implement solutions recommended in earlier reports. Those implemented to improve water quality include construction of various ponds with sensing devices for spills, planting of vegetation near the creek at the treatment plant, removal of underground storage tanks, evaluation of the Industrial Waste System at the airport, and examination of stormwater quality from the airfield.

City of Des Moines Monitoring

The City of Des Moines is currently conducting a five year monitoring effort to establish baseline conditions and evaluate the effectiveness of stormwater management efforts. The program is in its second year and the results are summarized in an annual report (Herrera, 1995).

Pollutant tracking is occurring as part of the City of Des Moines' five-year effort. Results are presented in an annual report (Herrera, 1995). Field inspection of stormwater outfalls occurred during dry weather in October 1994 at which time nine outfalls to Des Moines Creek were examined and seven were flowing. The outfall/catchbasin at South 216th Street and 12th Avenue South had an odor indicating possible sewage contamination, although a water sample collected at the catchbasin had low fecal coliform concentrations (22 /100ml). These results under dry conditions do not indicate an illicit sanitary sewer connection to the storm drain system. Herrera concluded that the absence of excessive turbidity and oily sheens in the outfall indicated that wastewaters were not being discharged into the storm drain system during their dry weather inspection. However, further investigation may be warranted during storm conditions to determine if ground water contamination by failing septic systems is a possible source of odor.

Port of Seattle Monitoring

The Port of Seattle is currently conducting a comprehensive study on the relationship between stormwater discharges from the airfield and water quality of Des Moines Creek. The project involves coordinated sampling of stormwater outfalls and stream stations during several storms, the purpose of which is to estimate the relative contribution of pollutants from the airfield to the total quantity of pollutants observed at the same time in the stream. The study is also examining water quality conditions in the Northwest Ponds, and its relationship to conditions in the stream. Because this study will not be completed until mid-1997, not all of the data are yet available for inclusion in this basin plan. The Port was able to provide data on stream water quality taken during storms in 1996. These data are incorporated in this basin plan, and are in general consistent with previous studies.

The Port has been monitoring the quality of stormwater from its outfalls since mid-1994 as required by its NPDES permit. The Port has published two reports summarizing the data with analysis (Port of Seattle, 1995; 1996). The data generally indicate that the concentrations of pollutants from runway outfalls are lower than from other urban land development like commercial and residential areas. Concentrations of pollutants in stormwater from the area of landside (that is, public access roads and parking) are typical of similar public activities. Comparison of data taken from July 1, 1995 to June 30, 1996 and data taken during the previous 12 months (July 1, 1994 to June 30, 1995) indicate that the loading of pollutants has decreased. This decrease is believed (Port of Seattle, 1996) to be due to various actions taken by the Port as described in its Stormwater Pollution Prevention Plan (SWPPP) (Port of Seattle, December, 1995). Samples taken during and/or immediately following deicing events found deicing chemicals, although in less than 50% of the samples (Port of Seattle, 1996). As described in its SWPPP, the Port is making modifications to its drainage system to reduce these emissions. These modifications are to be completed by mid-1997.

3. EXISTING CONDITIONS AND PROBLEMS

This chapter summarizes information developed during the project team's initial examination of conditions and existing problems in the Des Moines Creek watershed. Information in this section was drawn from existing studies and from interviews with knowledgeable individuals. Problems and potential solutions identified represent the state of information prior to analytical work performed for this effort, and are presented to document the evolution of our understanding of the stream system.

3.1. Overview of Urban Effects on Streams

Urbanization in the Puget Sound principally involves the conversion of forest into impervious areas such as roadways, parking lots, and roofs. This change in land cover produces profound changes in the hydrology of the stream system. When rain falls on the forest it is slowed and absorbed by the vegetation. Some of the moisture evaporates; some is used by the plants; some absorbs slowly through the decaying vegetation on the forest floor and is recharged to ground water; and a small portion actually ends up in the stream channel. Water that accumulates on the forest floor and in the shallow ground water system feeds the stream system during the summer months, when rainfall is scarce.

When rain falls on urbanized areas, the effect is vastly different. Instead of falling on trees and shrubs the rain falls on lawns, driveways, roofs, and roads. Rather than being used by the plants or being recharged slowly into the ground water system, the rain immediately becomes runoff and fills the streams. Instead of a slow increase in flow after a rainfall, the stream experiences a rapid rise to a much greater flow level followed by a rapid return to pre-storm flow levels. This change in streamflow characteristics (hydrologic conditions) in turn produces significant changes to the ecology of the stream. Flows vary over a greater range, in a shorter time period. Erosion increases, often dramatically. In-stream habitat for fish and other creatures is washed away or filled with sediment, and there are fewer animals in the stream. Water quality is degraded from oils and metals washing off of parking lots and roads, and pet wastes, fertilizers and herbicides washing off residential areas.

The changes which urbanization produces in the stream system also impact human activity. Erosion from increased flows threatens roads, bridges and pipelines. Sediment fills culverts and pools causing increased flooding. Flooding damages buildings and roadways. Water quality degradation increases the risks to human health and closes shellfish beds to harvesting.

3.2. Geology

3.2.1. Geology Conditions

The geology of the Des Moines Creek basin typifies conditions found throughout west-central King County. The upland plain is mantled by a rolling surface of glacial till, deposited during the last occupation of the Puget Lowland by a great continental ice sheet about 15,000 years ago. Coursing between the hills of this upland surface, and in places lapping up onto their flanks, are the channel deposits (outwash) of equally long-vanished rivers that issued from the snout of the retreating ice sheet as it withdrew to the north.

Beneath the surface till and outwash deposits is a complex sequence of older sediments that extend far below sea level. They are exposed at the ground surface where modern erosion has sliced through the glacial till. The most notable exposure of sediments are found along Des Moines Creek below the Tyee Golf Course. These older sediments are very compact, having been weighted down by at least one episode of glaciation subsequent to their deposition. Many are also cemented by oxidation, a consequence of the many tens or hundreds of thousands of years of weathering that they have experienced.

The distribution of geologic materials influences nearly every aspect of stormwater runoff and stream-channel processes. Precipitation falling on the areas underlain by glacial till is confined to a shallow layer in the overlying soil. Saturation of this soil zone is relatively common, forcing any additional water to flow rapidly across the ground surface. Soil compaction can dramatically lower the rate at which these till-derived soils can absorb rainfall, including the compaction caused by low-level landscaping activities. Any precipitation in excess of this lowered infiltration rate will run off rapidly.

In contrast, precipitation falling on the areas underlain by “outwash,” the sand-and-gravel channel deposits of glacial rivers, is absorbed rapidly and is only slightly affected by compaction. These deposits are typically several tens of feet in thickness, and so their capacity to hold the infiltrated rainfall is rarely exceeded. Although not the predominant deposit across the Puget Sound region, outwash was the main deposit in the area of the Des Moines Creek basin prior to construction of SeaTac International Airport.

The valley of Des Moines Creek crudely follows the path of one of the glacial-age outwash channels. Two tributary valleys, the easterly valley including Bow Lake (and now partly buried by the airport fill) and the westerly valley that lies southwest of the airport, converge in the Tyee Golf Course just north of South 200th Street. These valleys then continue south and eventually southwest to approximately the modern outlet of the basin. Both the glacial and the modern channels drain to Puget Sound. Whereas today the elevation of Puget Sound is fixed by sea level through the Strait of Juan de Fuca, during glacial time that level was controlled by the spilling of water south over the Black Hills into the Chehalis River. This was caused by several thousand feet of glacial ice that still filled the Strait of Juan de Fuca. Although the elevation of the Black Hills spillway was only a little over 100’ elevation, the land surface of the entire Puget Lowland has “rebounded” since that time because of subsequent removal of the not-inconsequential weight of the ice sheet. More rebounding occurred in the north than in the south, because the ice was thicker to the north. In the area of the Des Moines Creek basin, rebound was nearly 200 feet, and so the level of Puget Sound during active deposition of the outwash can be recognized today at about 300 feet elevation (about the level of the Tyee Golf Course, equal to the ponded level of water in Puget Sound plus post-glacial rebound).

As the glaciers continued to melt, the site of major outwash deposition rapidly shifted northward as it followed the retreating ice margin. Relatively soon after that shift, Puget Sound was lowered to its modern elevation; glacial rebound required an additional several thousand years.

The next glacial melt-water channel to the north is presently occupied by the valley of Miller Creek.

As a result of these changes to the drainage system, Des Moines Creek occupied a landscape much different from its current appearance during the first few thousand years after deglaciation. The creek drained only a few square miles (as today), but it wandered through a valley carved by discharges from the melting ice sheet which were many hundreds of times greater than flows the creek can now produce. Rather than sloping down to the Sound, it meandered across broad upland flats and then plunged abruptly over an escarpment into the marine waters several hundred feet below.

The resulting landscape modifications produced by post-glacial Des Moines Creek have been slow but inexorable. The modifications affect both the natural and the human environment in the lower part of the basin. The channel has incised through the upper glacial and lower mixed deposits, reestablishing a graded profile into Puget Sound. However, that process is not complete today, as it reaches only about 1.7 miles upstream to the southern edge of the wetland complex south of South 200th Street. Downstream of this point, the Des Moines Creek ravine is an isolated, protected environment which has discouraged most human activity and has limited the number of stream crossings. Upstream of this point the landscape is still one inherited from glacial activity, save the limited changes in the immediate vicinity of the stream channel itself and the not-so-limited changes as a result of human development.

The magnitude of channel erosion along Des Moines Creek is ultimately a consequence of this glacial origin, but the present-day locations of that erosion have been more specifically determined by several factors:

- urban development--intensity and history;
- erodibility of the underlying sediments; and
- channel and valley-wall gradients.

Urban Development

The profound landscape alterations by human development have been superimposed on the natural post-glacial changes affecting Des Moines Creek. Few basins in western Washington have seen the magnitude of disturbance and level of impervious-area cover as the Des Moines Creek basin. Although the consequences to Des Moines Creek and the human population of the basin have been significant, they are not as severe as in many other places within the region. There are several reasons for this:

- Widespread area of pervious outwash soils, still not wholly blanketed by concrete and asphalt;
- A large volume of stormwater storage, both artificial and (particularly) natural, in the lakes, wetlands, and stormwater facilities of the basin;
- Relatively compact and non-erosive deposits along most of the stream-valley sidewalls;
- A five-year period of relatively low discharges (which ended on February 8, 1996);

- The *age* of urban development, which is one or more decades old nearly everywhere and, in the case of the central airport area, over 30 years old. As a result of development, the channel has had an opportunity to partially re-equilibrate to the development-altered hydrologic regime. Indeed, removal of houses in the airport's buyout zone may have actually *reduced* the net impervious area in certain sub-basins over the last decade;
- Open space and vegetation along ravine; and
- The diversion of some storm flows out of the stream channel by the operation of the IWS at SeaTac International Airport.

Measured channel dimensions are virtually identical to other urbanized basins in King County of equivalent size, even though the Des Moines Creek basin has a higher percentage of impervious land cover (see Figure 3.1). The degree of active channel erosion usually expected to be larger in basins with greater impervious cover is somewhat *less* here than elsewhere.

Sediment Erodibility

The degree of damage to hillslopes and aquatic systems from past land use activity is significantly less in the Des Moines Creek basin than in many other locales. In particular, the release of culverted discharge at the top of steep slopes has resulted in problematic but nevertheless non-catastrophic soil erosion in the creek, coupled with modest downstream deposition. Such discharges have caused 60-foot-deep ravines, road closures, and multi-million dollar lawsuits elsewhere.

The reason for this difference lies in the consolidation and cementation of the valley-wall sediments here, which in turn is a product of the region's geologic history. Across the entire Puget Lowland, the single most voluminous deposit is sand from the last glaciation. The sand was deposited *in advance* of the expanding ice sheet ("advance outwash") as opposed to the more limited, channelized sand-and-gravel deposits left by the *retreating* ice sheet ("recessional outwash") so common here in the Des Moines Creek basin. The advance outwash typically underlies the glacial till and may be 100 to as much as 300 feet thick. For example, 200 feet of sandy advance outwash is exposed immediately north of the mouth of the basin along the beach cliffs fronting Puget Sound; three miles north, at Three Tree Point in Burien, the advance outwash extends from below sea level up to an altitude of 380 feet without a break.

Although advance outwash is certainly present beneath part of the Des Moines Creek basin, it is almost entirely absent along the central ravine. This is virtually the only place where post-glacial erosion has thus far incised through the recessional outwash and till. As a result, hillslope erosion from errant stormwater discharges has resulted in some loss of the overlying soil layers but no catastrophic downcutting.

3.2.2. Geology Problems

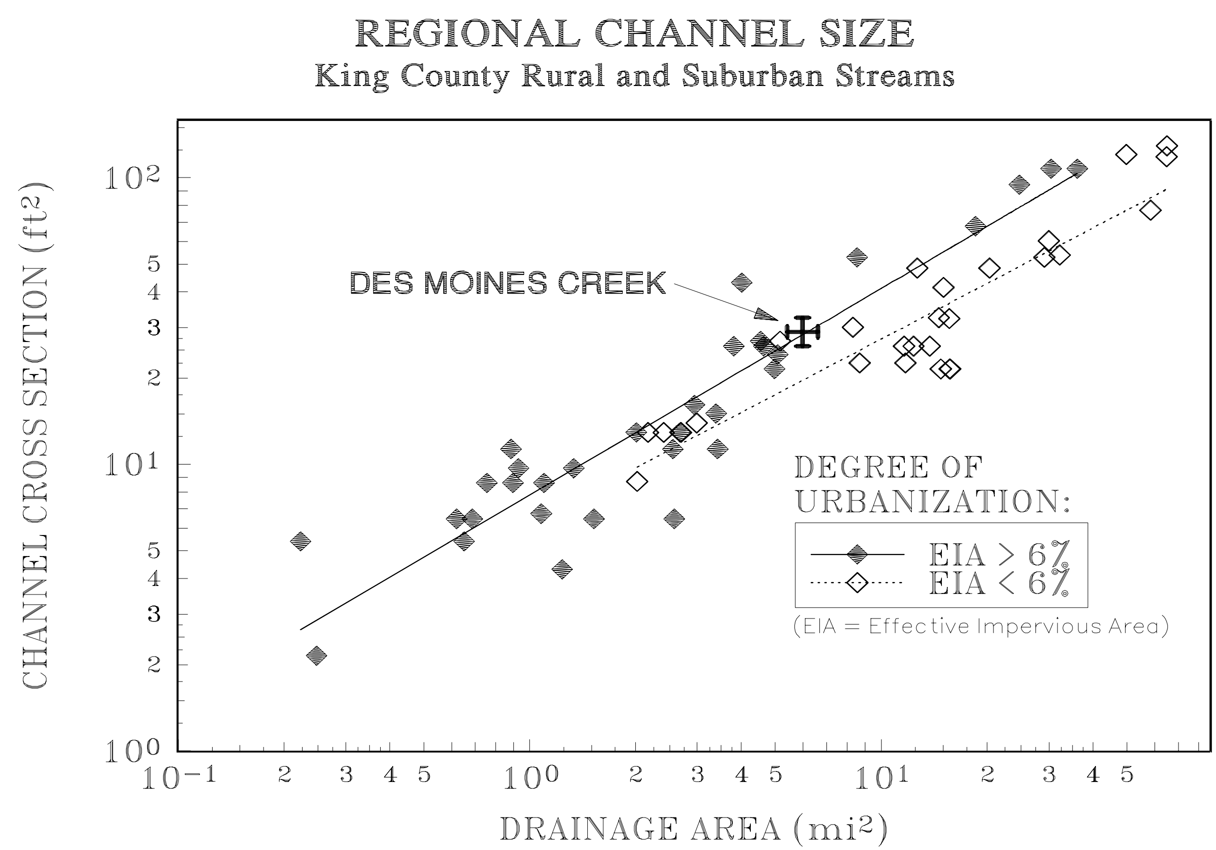
Nearly all of the geologically determined problems in the watershed are localized to the steep hillslopes adjacent to the central ravine of the basin. Most severe are two shallow hillside failures just upstream of the road fill of Des Moines Memorial Way, one entering the creek at RM 0.45 and the other at RM 0.55, which both originated from top-of-slope release of discharge to culverts from the roadway storm drainage system. During the February 1996 storm, both of these discharges initiated debris flows that carried a substantial sediment load down to the sewer-line access road and then into the creek itself, several hundred feet below. The road shoulder was undermined not only at these two outfalls but also at a third location between these two, where uncontrolled road runoff has been allowed to run from the pavement directly onto the hillslope below. The upstream culvert failure also required repair following storms in 1995.

Other hillslope erosion sites are a result of uncontrolled road-end discharges. The largest of these is the expansion of a natural channel that enters Des Moines Creek from the south at RM 1.35 and which now accepts additional runoff from 18th Avenue South, north of 216th Street South, in the buyout zone. Up to eight feet of incision, none of it apparently very recent, occurs at the lower end of the channel. Some erosion of a dirt road that continues from the road end down to the creek is ongoing. The only other problematic sites appear to be at the road end of 14th Avenue South at South 212th Street, running into the central ravine at about RM 1.12, and a cross-culvert at the intersection of 6th Avenue South and South 218th Street. Both contribute minor amounts of sediment to the channel; neither pose any but the longest-term hazard to the upslope roadways.

Channel-bank erosion along Des Moines Creek is locally quite problematic. This is less for the absolute magnitude of the erosion than for the proximity of the within-valley sanitary sewer line. Two conditions favor such erosion: excessive confinement of the original valley width by the fill surrounding the sewer line and its overlying access road, and the local orientation of the meandering stream flow which sporadically impinges on the fill directly. Multiple sites display these problems.

The best solutions to these problems are not uniform along the channel network. Downstream of the treatment plant at about RM 1.0, the valley of Des Moines Creek is relatively wide; protection of the sewer-line fill using bioengineering techniques would, in nearly every case, serve to protect the utility and enhance the habitat value of the channel with few or no adverse affects. However, upstream of the treatment plant the valley is much more confined and the sewer-line fill occupies a proportionately greater fraction of the total valley width that was once available to the creek. Any diversion or armoring of the right bank of the channel, adjacent to the fill, will divert flow against an often equally steep left bank. Under these circumstances, the blanket application of a particular bank-stabilization method cannot be specified with as much certainty. Site-specific circumstances will determine if there is flexibility to install more beneficial, but more space-consuming, vegetative or hybrid rock-and-plant measures.

Figure 3.1 - Regional Channel Size (cross section vs. drainage area)



3.3. Hydrology

3.3.1. Hydrology Conditions

The unique stream flow characteristics of the Des Moines Creek system are determined by the literal superposition of intense urbanization over an otherwise hydrologically placid landscape composed of infiltrative soils, and a drainage system damped by a lake and large wetlands. With nearly a third of the 5.8-square-mile drainage basin currently covered by impervious surfaces the creek rises, peaks sharply, and falls rapidly in response to even moderate storms. In contrast, the remaining two-thirds of the basin is predominantly outwash and till derived soils which make little contribution to flood peaks in the creek since they are highly to moderately pervious and vegetated. Instead, pervious areas supply stream flow during the periods between storms in winter, sustain summer base flows, and act as a conduit through which significant amounts of water escape the surface drainage system by deep percolation and/or shallow, ground water discharge.

Given the characteristics of the basin, the current level of land development has surely increased the peak discharges in the creek system and created observed erosion and flooding problems. However, because of the natural damping characteristics of the soils and drainage system in the basin, these peak flows are smaller than would typically be observed for a basin of this size and land-use composition. As future buildout replaces remaining pervious areas, hydrologic impacts will continue to increase significantly and cause additional problems unless effective measures are implemented.

This observation is illustrated by Table 3.1 which summarily compares flow conditions in the mainstem of the creek under current and future buildout conditions to what they were under pristine, forested conditions. As shown, peak annual flows (average of 2, 5, 10, 25, 50 and 100-year discharges) are currently greater than four times what they were under pre-development conditions. This will increase from 20 percent to five times their historical levels at buildout. Even more dramatic, the erosivity and sediment transport capacity of storm flows in the creek have increased by a factor of 25 currently and will double in the future. Similarly, construction of impervious surfaces has resulted in a reduction in summer base flows by a factor of .79 (a loss of 21 percent) while it is expected that buildout will increase the factor of reduction to .59 (or a loss of 41 percent).

Table 3.1 Summary of Hydrologic Change in Des Moines Creek Ravine*

Hydrologic Characteristic	Current/forested	Future/forested
Peak Annual Flow Ratio	4.1	5.0
Stream Erosivity Ratio	25	55
Summer Base Flow Ratio	.79	.59

* Comparing current or future conditions to pre-development, forested conditions

3.3.2. Hydrology Problems

Problems in the Des Moines Creek system are the result of a typical progression: land development removes native vegetation and replaces pervious soils with buildings, roads, and other impervious surfaces; storm runoff from these surfaces is not sufficiently controlled; storm flows in the creek increase dramatically; downstream flooding, channel erosion, and water quality degradation result. In addition to these peak flow-related problems, land development also cuts off infiltration and recharge of slow moving ground water that sustains summer base flow of creeks. Reductions in base flow generally decreases fish habitat, and potentially aggravates excessive stream temperatures and other water quality-related problems.

The case of the Des Moines Creek basin is classic. Including construction of the cities and the SeaTac Airport, urbanization has stripped the basin of its forest cover and replaced 30 percent of the drainage area with impervious surfaces. Meanwhile, understanding of the need to control the quantity and quality of stormwater from impervious surfaces has evolved significantly but has greatly lagged the urbanization process in the Des Moines Creek basin. Consequently, the current installed capacity of drainage controls such as retention or detention ponds is much less than would be called for by the most up-to-date standards. This has resulted in greatly increased frequency and duration of peak discharges causing significant problems such as:

- frequent flooding and damage to public buildings and facilities in Des Moines Beach Park;
- channel erosion and damage to the sewer pipeline access road in Des Moines Creek ravine; and
- scour of spawning gravel and reduction of spawning area by complete removal of spawning material in portions of the mainstem of Des Moines Creek.

3.4. Water Quality

3.4.1 Pollutant Sources and Critical Land Uses

Urban Areas

The water quality in Des Moines Creek and its tributaries is intricately linked to the activities occurring on the land surface. As it is primarily an urban basin, nonpoint source pollution from human activities is the primary source of pollutants into the creek. Land uses in the basin that are likely to contribute the majority of nonpoint source pollution include urban development and roadways, land conversion, failing septic systems, large areas of pavement used for transportation such as highways and airport runways, and possibly the Tyee Golf Course.

Significant urban sources of pollutants in the basin include vehicular traffic, street litter, residential and commercial fertilizer, construction activities, and metal corrosion. Motor vehicle traffic is a major pollutant source in most urban basins such as Des Moines Creek and is the direct source of substantial amounts of pollutants including toxic hydrocarbons (gasoline and oil), asbestos (brake and clutch linings), and metals (copper, lead, and zinc) (Novotny and Olem, 1994). Sources of metals include tire wear, brake linings, exhaust fumes, galvanized flashing and other exterior metal products, and roadway abrasion. In addition to vehicular pollutants, sediment originating from street dust and litter accumulation on impervious surfaces (and localized yard erosion) can produce a significant sediment load; pet populations can, and often do, contribute a significant amount of fecal coliforms in urban runoff. In Des Moines Creek, wildlife activity such as the large number of waterfowl at Bow Lake are also believed to be contributing to elevated fecal coliform levels.

Although the erosion and sedimentation impacts during construction are temporary, the impact of erosion and sedimentation from disturbed sites is a significant source of sediment and phosphorus. The basin is currently 30 percent impervious and is predicted at buildout to increase to 42 percent impervious. Increases in sediment yield caused by land use changes have been well-documented (Wischmeier and Smith, 1965; Novotny and Olem, 1994). Sediment yields from developing urban areas can be extremely high, sometimes reaching values in excess of 100,000 tons per square mile per year (Novotny, 1980; Novotny and Chesters, 1981). Sediment yields, and the resulting nutrient enrichment and habitat degradation, are much smaller than this at the present. Analysis of future conditions indicates this could develop in to a significant issue for Des Moines Creek, particularly if any fills occur in the vicinity of the creek.

Septic Systems

Failing septic systems and/or illicit sewer connections to storm drains appear to be a significant source of pollution in Des Moines Creek. Septic pollution has two pathways to the creek: (1) shallow subsurface transport of dissolved pollutants (mainly nitrate) during baseflow, and (2) surface runoff from failing septic systems as a result of high water tables, poorly drained soils, or short-term surface saturation during storms. Instream stormwater quality data collected by the City of Des Moines show locally elevated levels of fecal coliform bacteria under both storm and baseflow conditions and elevated nitrogen conditions under storm conditions, all of which can be released from septic systems or illicit connections. These results prompted King County Water and Land Resources (formerly Surface Water Management) Division to collect further samples for RNA fingerprinting of the fecal coliform bacteria. The results of the RNA analysis, though incomplete, implicate human and septic sources as a major source of fecal contamination. See Appendix B for details of the RNA analysis.

Although no formal survey was conducted, a review of sewered and unsewered areas performed previously by King County Planning and Community Development shows a portion of the basin as unsewered (see Figure 3.2). The unsewered area includes portions of the golf course and areas of older single-family homes (greater than 15 years of age) at both high and low densities, many of which have septic problems due to their age and density. Many of the septic systems in this area are at or near their 15-30 year design life and were designed under standards that allowed smaller lots and a thinner soil depth. RNA typing results revealed a dominance of human/septic fecal strains downstream of the unsewered area. In headwater areas, 50 percent or more of the strains remained unmatched, and for the matched strains, avian and canine sources equaled or exceeded human sources. In contrast, for samples taken at RM 0.9 just downstream of the unsewered area identified in Figure 3.2, 64 percent of the strains matched human/septic sources and only the remaining 36 percent remained unmatched. Septic fecal contamination of Des Moines Creek is likely to continue or worsen over time, especially with the predicted infilling of high density development, unless sewers are installed in areas not currently served.

Septic systems also occur in areas which are served by sewers. During installation of new sewer lines, it is often voluntary whether individual properties connect to the new sewer system or not. It is likely that a number of homes within the areas served by sewers are not connected. These homes are also suspected of being a source of fecal coliform contamination. The unconnected houses in areas served by sewers could be a significant source of contamination depending on the age of the systems, the number of unconnected houses, and the quality and depth of surrounding soils in the immediate area. Current regulations require existing homes with failed septic systems to connect to the sewer system if the house is within 330 feet of sewer lines.

Although there is little agricultural land uses or pastures, domestic animals in the residential areas and waterfowl on the golf course and Bow Lake are suspected to contribute a significant fecal coliform loading to the Creek. Previous investigations (Herrera, 1995) believe domestic animals may be a significant source of fecal coliforms in the Des Moines Creek basin. RNA results confirm the presence of avian and canine fecal strains in these areas; bovine and deer/elk sources were also noted, but these results are suspected to be erroneous.

Tyee Golf Course

Previous studies indicate that the Tyee Golf Course may be contributing phosphorous and nitrogen to the creek from fertilizer application. Conversations with the current managers indicate that best management practices, including reasonable application rates and frequencies for fertilizers are employed. However, investigation of actual application rates and location to sensitive areas was not conducted as part of this study. The large area of the managed turf and high levels of phosphorus in the creek may warrant further investigation of the golf course fertilizer application practices**.** The golf course is also habitat for many wildlife, including birds. Previous studies have suggested that these birds may be contributing to the fecal coliform contamination levels. Information developed during this study indicates birds are not a significant source of fecal contamination.

Sea-Tac International Airport

The airfield has two drainage systems: the storm drainage system (SDS) and the industrial waste system (IWS). The SDS drains generally the runways, taxiway and building roofs. It also serves the public, or landside, area of the airfield such as the access roads and parking areas located between the airfield and International Boulevard. The IWS drains generally the areas around the cargo and passenger terminal areas and some landside parking lots along Air Cargo Road. The stormwater and miscellaneous wastewater generated in the IWS drainage system flow to one of three storage lagoons, from which they are removed for treatment by the industrial wastewater treatment plant. Treated waters are discharged to Puget Sound via an outfall system used jointly with the Midway Sewer District.

When infrequent, extreme storms occur that exceed the capacity of the lagoon system, limited discharges may occur from one or more of the three lagoons. Each lagoon has a designated point for these discharges to occur that prevent damage to the lagoon. Discharges from Lagoons 1 and 2 enter a road ditch along the north side of South 188th Street, which is connected to a storm drain line that extends from the road ditch directly south to the northwest corner of the Northwest Ponds. Discharges from Lagoon 3 enter a natural swale that carries stormwater from an airfield SDS outfall (SDS3) to the northeast corner of the Northwest Ponds. Discharges that exceed the capacity of the lagoon system are allowable under the Port's NPDES permit. Since 1981, three discharges have occurred: October 6, 1981; December 4, 1989; and October 31, 1994. The first event lasted approximately two hours; the second event lasted less than two hours; the third event lasted approximately thirty minutes. Of the three events, the discharge volume was estimated for only the last event. It was estimated to be 40,000 gallons. This estimate suggest that the volumes of the other two events were small relative to the volume of stormwater flowing through the Des Moines Creek system at he time of each respective event.

The fueling of aircraft and ground support vehicles is restricted to areas that drain to the IWS. Consequently, spilled fuel will typically not enter the SDS. Two major fuel emissions occurred in the mid-1980s: one each from the Olympic Tank Farm and the Northwest Fuel Farm. These emissions reached Des Moines Creek. The emission from the Olympic Tank Farm reached the creek because at that time the stormwater collected from around the farm entered a pipe that discharges to the creek. However, subsequent to this release, the area within the berm that surrounds the farm was connected to the IWS. All stormwater collected within the farm enters the IWS; it is physically impossible for stormwater to enter directly into the creek from the farm. Regarding the Northwest Fuel Farm, changes were made to the equipment such that the type of emission that occurred in the mid-1980 cannot repeat itself. In addition, one purpose of the Tyee Detention Pond, built subsequent to the above spills, is to retain spills that may reach the creek from outfalls that discharge into the east tributary.

The Port of Seattle has been monitoring the quality of the stormwater from its outfalls since mid-1994 as required by its NPDES permit. The Port has published two reports summarizing the data with analysis (Port of Seattle, 1995; Port of Seattle, 1996). The data generally indicate that the concentrations of pollutants from runway outfalls are lower than from other urban land development like commercial and residential areas. Concentrations of pollutants in stormwater from the area of landside (public access roads and parking) are typical of similar public activities. Comparison of data taken from July 1, 1995 through June 30, 1996 to data taken the previous 12 months, July 1, 1994 through June 30, 1995, indicate that the loading of pollutants has decreased. This decrease is believed (Port of Seattle, 1996) to be due to various actions taken by the Port as described in its Stormwater Pollution Prevention Plan (SWPPP) (Port of Seattle, December 1995). Samples taken during and/or immediately following deicing events found deicing chemicals, although in less than 50 percent of the samples (Port of Seattle, 1996). As described in its SWPPP, the Port is making modifications to its drainage system to reduce these emissions. These modifications are to be completed by mid-1997.

3.4.2. Water Quality Classification

Des Moines Creek is classified by the WSDOE as "Class AA" (extraordinary). This is an administrative designation based on desired uses of the water body and is only roughly based on the water quality of the stream system at the time of designation. Class AA waters should be useable for water supply, stock watering, fish and wildlife habitat and recreation. Very few urban streams meet Class AA standards consistently. Table 3.2 describes the Washington state surface water standards for Class AA waters.

Des Moines Creek is also on the WSDOE 1996 list of "troubled waters" (303d list) due to elevated levels of fecal coliforms. This listing of Des Moines Creek as a troubled water reflects monitoring results which show state water quality standards for fecal coliform levels are not being met. Fecal contamination is the most common water quality problem in urban areas such as Des Moines Creek.

Table 3.2 Washington State Surface Water Quality Standards for Class AA Freshwater

Parameter	Standard
Fecal coliform bacteria	Shall not exceed a geometric mean value of 50 organisms/100 ml, with not more than 10 percent of samples exceeding 100 organisms/100 ml.
Dissolved Oxygen	Shall not exceed 9.5 mg/l
Total dissolved gas	Shall not exceed 100% saturation at any point of sample collection
Temperature	Shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increase will be allowed that raises the receiving water temperature by greater than 0.3°C. Incremental temperature increases from nonpoint source activities shall not exceed 2.8°C.
pH	Shall be within the range of 6.5 to 8.5 with a human caused variation within a range of less than 0.5 units.
Turbidity	Shall not exceed percent NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when background turbidity is more than 50 NTU.
Toxic, radioactive or deleterious material concentrations	Shall be below concentrations that have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent on those waters, or adversely affect public health, as determined by Ecology.
Aesthetic values	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the sense of sight, small, tough or taste.

Source: WAC 173-201A

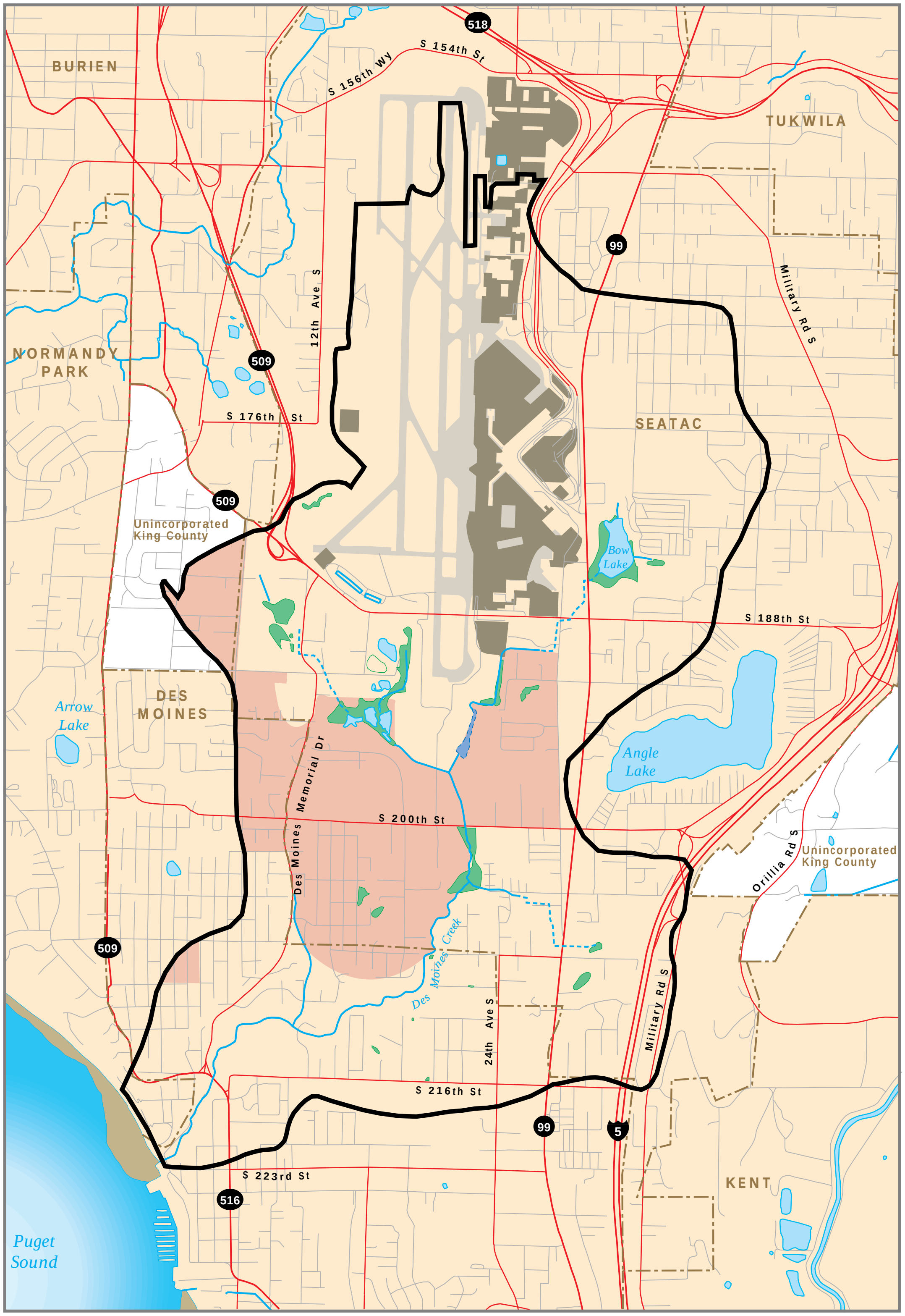


Figure 3-2

DES MOINES CREEK BASIN

Unsewered Area

Approximate Unsewered Area
Basin Boundary
Stream
Piped Stream
Incorporated Area
Industrial Wastewater System
Lake
Wetland
R/D Facility

N

0 1/2 Mile

October 1997

Map produced by: King County
DNR GIS/Cartography/Graphics Unit

Sewered Area Sources:
City of SeaTac Comprehensive Plan, 1994
King County, Planning and Community Development GIS Database

9710DMunsewered3-2.pdf WG

3.4.3. Current Monitoring Programs

The City of Des Moines and the Port of Seattle have ongoing water quality monitoring programs. Sampling locations are summarized on Figure 3.3. A summary table of both monitoring activities is presented in Table 3.3. This study incorporated their data and analyses when available.

Table 3.3 Summary of Ongoing Water Quality Monitoring Programs in the Des Moines Creek Basin

Data Type	City of Des Moines	Port of Seattle
Stormwater-instream	Composite or grab instream sample: temp, pH, DO, conductivity, hardness, turbidity, TSS, TP, NH3, NO3+NO2, metals (Cu, Pb, Zn-total and dissolved), TPH and fecal coliform	Automatic instream samplers: temp, pH,flow, TSS, BOD, NH3, hardness, metals (Cd,Cu,Pb,Ni,Ag,Zn-total recoverable and dissolved), TPH, microtox and glycol if deicing is occurring
Stormwater outfalls		Automatic samplers: flow, pH, FOG, TSS, turbidity, fecal coliform, BOD5, NH3, metals (Cd,Cu,Pb,Ni,Ag,Zn-total recoverable and dissolved), TP, microtox
Baseflow	grabs: flow, temp, pH, DO, cond., hardness, turbidity, TSS, TP, NH3, NO3+NO2, metals (Cu, Pb, Zn-total and dissolved), fecal coliform	
Stream Deicing		Flow, temp, BOD, glycol, NH3, microtox
Stream Sediment		Metals (Zn, Cu, Pb, Al), grain size, percent fines, TOC, TPH, TPH, HCID, TKN, pH, sulfides, VS, TP

Des Moines

The City of Des Moines began a five year monitoring program in October 1994. The primary objective of the City's program is to collect comprehensive data for evaluating trends in water quality in the three stream basins within the city: Des Moines Creek; Massey Creek; and McSorley Creek. Results of the monitoring program and historical sources will be used to assess the effects of a stormwater management and nonpoint source control program implemented under the City of Des Moines Comprehensive Stormwater Management Plan. Data from 1994-1995 and fall through spring of 1996 were included in this analysis (1995 Annual Report-City of Des Moines Water Quality monitoring Program, October 1995; unpublished data 1996).

The Des Moines monitoring program is composed of stormwater and baseflow monitoring, pollutant source tracking and biological monitoring. Stormwater water quality samples are collected at stations upstream near the City limits at the Midway Sewer District Wastewater Treatment Plant and downstream located at the mouth of the creek in the park. Baseflow monitoring occurs at South 200th Street, on the east branch of the creek upstream of the confluence with the West branch, west branch of the creek upstream of the confluence with the east branch, and on the east branch of the creek upstream of the Olympic Tank Farm.

Port of Seattle

The Port of Seattle is currently conducting a comprehensive study on the relationship between stormwater discharges from the airfield and water quality of Des Moines Creek. The project involves coordinated sampling of stormwater outfalls and stream stations during several storms, the purpose of which is to estimate the relative contribution of pollutants from the airfield to the total quantity of pollutants observed at the same time in the stream. The study is also examining water quality conditions in the Northwest Ponds, and its relationship to conditions in the stream. Because this study will not be completed until mid-1997, not all of the data are yet available for inclusion in this basin plan. The study is to cover eight general topics. These are:

1) Characterize Sea-Tac International Airport stormwater discharges - Sample the storm water outfalls for Total Suspended Solids (TSS), turbidity, ammonia, glycol.
2) Stream water quality - Identify the water quality of each stream during storms and the role of the SeaTac International Airport stormwater discharges in defining water quality.
3) Sediment Quality - Describe the chemical quality of sediment near SeaTac International Airport outfalls and their relative role in affecting sediment quality.
4) Constituent Loading - Determine stormwater loading from the outfalls and their relative contribution in comparison to other constituents sources in each basin.
5) Wetland Status - Determine the ecological state and functions of wetlands adjacent to the SeaTac International Airport and the role of the airport stormwater discharges. Wetlands include Northwest ponds.
6) Assessment of deicing impacts - Assess the potential impact of deicing chemical on the water quality and biota of the creek.
7) Quantify flow impact on streambank erosion - Assess the role of SeaTac International Airport stormwater on existing bank and channel.
8) Biological assessment - Assess biological health of creek including macroinvertebrates and fish communities.

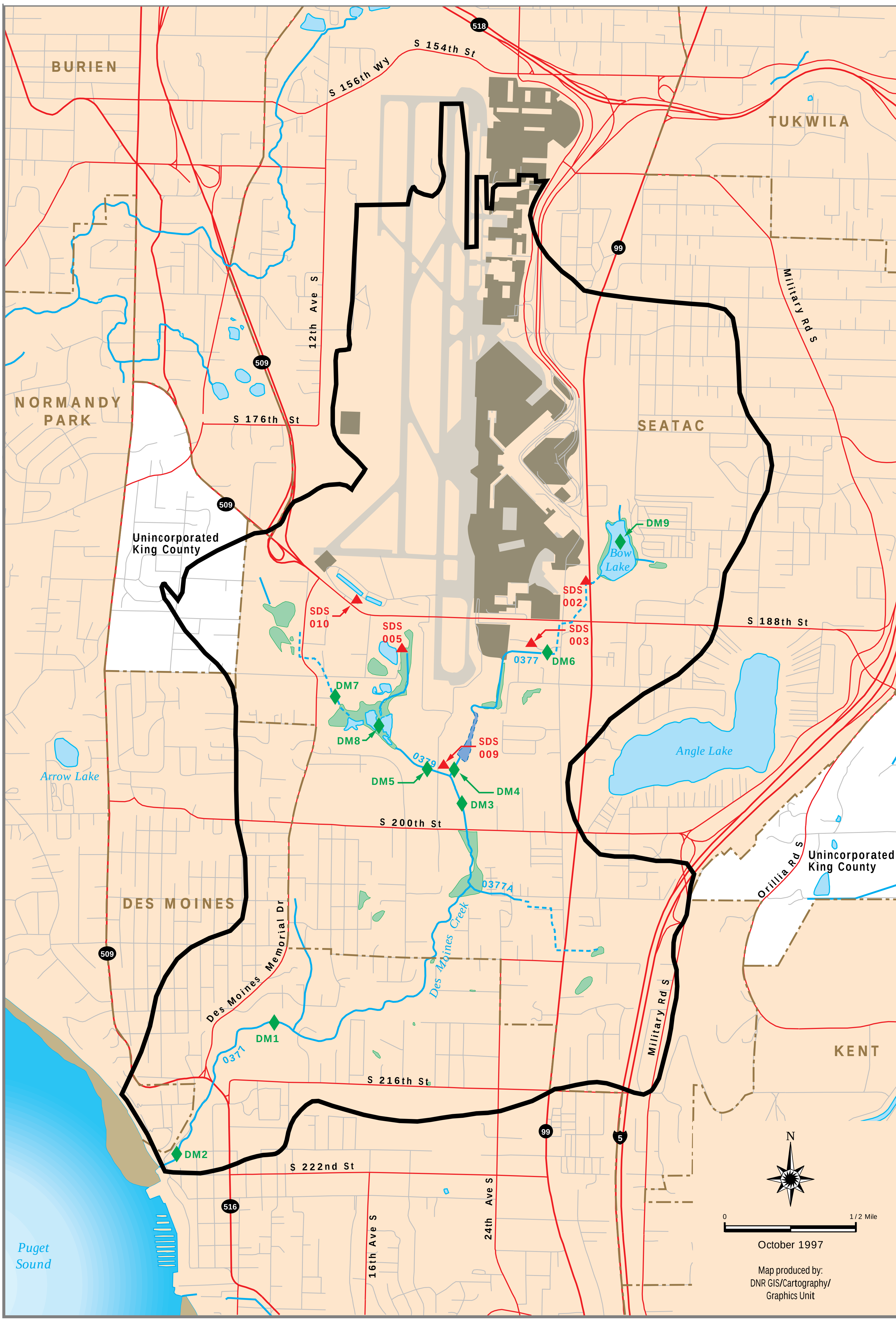


Figure 3-3

DES MOINES CREEK BASIN
Water Quality Sampling Locations

- DM1 City of Des Moines Monitoring Site
- SDS 001 Port of Seattle Outfalls
- Basin Boundary
- 0377 Stream/Stream Number
- Piped Stream
- Incorporated Area
- Industrial Wastewater System
- Lake
- Wetland
- R/D Facility

Base Map Notes:
All updates register to USGS PLS
Wetland Sources:
Port of Seattle Wetland Mapping, 1995
Map does not include wetland #22
Stream and Pipe Location Sources:
USGS Digital Line Graph
King County Basin Recon Program, 1987
Aerial Photos, 1989
Port of Seattle Field Mapping, 1995
Roadway Sources:
USGS Digital Line Graph
Aerial Photos, 1989
Industrial Wastewater System Source:
Port of Seattle Comprehensive Stormwater and Industrial Wastewater Plan
Contour Lines Source:
USGS Digital Elevation Model
Incorporated Areas Source:
King County GIS coverage

Sampling for NPDES work began in 1996, with the completed report scheduled for release in June 1997. Due to delays in laboratory analysis and preliminary analysis at the Port of Seattle, none of the data being developed as part of the NPDES program was available in time for inclusion in this draft Basin Plan.

In reviewing the monitoring efforts of the Port, it is important to understand the drainage patterns of the Port's properties. SeaTac International Airport drains to two basins: Miller Creek to the north and west and Des Moines Creek to the south. Of the approximately 1,050 acres located within the NPDES permit boundary, about 25 percent drains to the Industrial Waste System (then directly to Puget Sound), about 10 percent drains to Miller Creek and about 65 percent drains to Des Moines Creek. This report concerns only drainage directly to Des Moines Creek.

The Port maintains ten outfalls from Sea-Tac Airport, which are permitted and monitored as part of their NPDES stormwater permit. Six permitted outfalls from the airport drain southerly to Des Moines Creek: SDS1 through SDS4, SDE4 and SDW3. Two outfalls (SDE4 and SDS1) drain to the eastern tributary of the creek; the remaining four outfalls drain to the western tributary. Only two of the six outfalls discharge directly to Des Moines Creek, SDS1 (western tributary) and SDS4 (eastern tributary). Flows from outfalls SDW3, SDS2 and SDS3 enter the creek through the Northwest ponds situated on the western tributary. Outfall SDE4 discharges to a subsurface drainage pipe between Bow Lake and the east tributary at South 28th Street. Data have been collected since mid-1994 and are presented in two reports (Port of Seattle, 1995 and 1996).

3.4.4. Water Quality Problems

The water quality in the study area is typical of developed and urbanizing basins, showing increased contamination of stormwater and baseflow with respect to metals, total suspended solids, nutrients and fecal coliforms. The WSDOE believes that Des Moines Creek does not meet fecal coliform standards now and has placed the stream on its 303(d) list of "troubled waters."

Discussion of water quality analyses is covered in Appendix B of this plan. To summarize, the water quality results indicate typical urban conditions. Issues of concern are described below.

A. Turbidity and suspended solids concentrations increase substantially during stormflow conditions. Likely sources include surface runoff, bank erosion, and suspension of previously deposited particles in the stream bed. The observed levels of turbidity and suspended solids suggest high levels of bed scour during storms and subsequent deposition of fines and clogging of interstitial (between-rock) spaces upon return to baseflow. These conditions are of particular concern to the stream benthic community (the organisms living on or in the streambed) and to developing salmon embryos.

B. Nutrients in the stream (total phosphorus, ammonia and nitrate-nitrite) present a concern to the stream itself rather than its receiving water body because high levels cause excessive periphyton growth and accompanying localized oxygen depletion, particularly in Northwest Ponds. Mean storm flow concentrations of nutrients in the creek tended to be higher than mean values reported for other Seattle-area streams (Herrera, 1995).

C. Water temperatures regularly exceeded both the optimal upper temperature of 14°C for salmonid species present in Des Moines Creek and the Washington State standard of 16°C from April through September 1996. Although water temperatures measured during 1996 did not exceed the lethal limit for salmonids of 22°C, there were several periods of sustained high water temperatures during this period which created extremely unfavorable conditions for salmonids in Des Moines Creek. Although water temperatures in Bow Lake, the Northwest Ponds, and their respective outlets exceeded lethal limits for salmonids, the mainstem recovered to sub-lethal, yet highly stressful temperatures before it flowed past South 200th Street.

D. Concerns regarding dissolved oxygen concentrations are limited to the two headwater tributaries and mainstem Des Moines Creek above South 200th Street. Late summer dissolved oxygen concentrations fell as low as 2 mg/L in the West Fork and typically fell below 7 mg/L in the mainstem above the uppermost golf course weir. These problems stem from oxygen demand by algal blooms in Bow Lake and the Northwest Ponds and from extremely slow-flowing conditions in the tributaries, especially the West Fork. Dissolved oxygen concentrations do not appear to threaten aquatic life in Des Moines Creek below South 200th Street due primarily to reaeration from the three weirs immediately above South 200th Street. Concentrations at two monitoring stations below South 200th Street remained above the upper threshold for salmonid embryo impairment of 8 mg/L and generally met the 9.5 mg/L State standard.

3.5. Fisheries

The fish species currently using Des Moines Creek are basically the same species as historically utilized the creek: coho and chum salmon, searun cutthroat trout, a few steelhead, and with occasional pink salmon. Resident cutthroat trout are still present in Des Moines Creek, especially in the reach from Marine View Drive to South 200th Street. Small resident cutthroat trout, while not numerous, were the most common fish encountered in a recent electrofishing survey of this portion of the basin. On October 24, 1994, seven locations in Des Moines Creek from Marine View Drive South upstream to South 200th Street were electrofished (see Table 3.4). These locations were qualitatively electrofished (i.e., no block nets; no set distances; no population estimates) to simply identify the presence or absence of fish, species, and the size of fish.

Three species of fish were captured: cutthroat trout, coho salmon, and pumpkinseed sunfish. The most common fish captured, cutthroat trout, were found at all seven stations with a total of 48 cutthroat trout captured. The median length of these fish was 104 mm (range: 72 - 320 mm).

It appears that three age classes of cutthroat trout may be present in Des Moines Creek. Young of the current year are less than 100 mm in length but generally greater than 80 mm. Cutthroat trout older than a year but younger than 2 years old generally measure between 100 mm and 125 mm. Cutthroat trout older than two years old are generally larger than 125 mm. These conclusion are supported by Carlander (1969) who lists data for cutthroat trout from many locations.

Surprisingly, the second-most common fish captured was pumpkinseed sunfish. This was unexpected in that the pumpkinseed sunfish "appears to prefer clear, quiet water with dense aquatic vegetation in weedy ponds, lakes, and slow-moving rivers" (Wydoski and Whitney 1979). The source of pumpkinseed sunfish is likely Bow Lake and golf course ponds (both located upstream of South 200th Street). The median length of the 14 pumpkinseed sunfish captured was 56 mm (range: 35 - 65 mm). Pumpkinseed sunfish were captured at six of the seven locations electrofished.

Only two coho smolts were captured; both of these fish were captured at the most downstream station. These fish may be the result of natural reproduction from observed adult coho in this area.

Table 3.4 Results of Electrofishing at Seven Sites on Des Moines Creek (October 24, 1994).

		Total Length of Fish (mm)		
Location	**RM[1]**	**Cutthroat**	**Coho**	**Pumpkinseed**
Station 2800-3000	0.53 - 0.57	95, 108, 113, 130 81, 90, 98, 100, 105	100, 110	57 35
Station 3150	0.60	80, 130		41, 55
1st Most Downstream Log Weir near WWTP*	0.75	85, 85, 105, 113, 120, 320		54, 58
2nd Most Downstream Log Weir near WWTP*	0.75	92, 92, 95, 116, 120		
Station 7440	1.41	72, 85, 90, 90, 100, 113, 125, 180		45, 62
Ravine Reach	1.50	85, 90, 91, 94, 95, 110, 110, 115, 120, 144		40
Plateau (downstream of S. 200th Street)	2.0	95, 97, 102, 105, 110, 125, 128, 130		40, 60, 60, 60, 65

* Waste Water Treatment Plant
[1] See Figure 1.2 for RM locations

Des Moines Creek was again electrofished in August 1996. Four locations were qualitatively electrofished (i.e., no block nets; no set distances; no population estimates) to identify the presence or absence of fish, species, and the size of fish. Six species of fish were captured: steelhead (rainbow), cutthroat trout, hybrid rainbow/cutthroat trout, large mouth bass, pumpkinseed sunfish, and sculpin (Table 3.5). No coho salmon were captured during this sampling. Most steelhead were captured in the park reach. Hybrid trout were most common in the plant reach; only cutthroat trout were captured in the ravine reach. The largest fish found during this sampling were upstream of South 200th Street, where five cutthroat trout ranging in length from 162 - 260 mm were captured.

Table 3.5 Summary of Electrofishing Data from Des Moines Creek on August 19, 1996.

	Species				
	Steelhead	Cutthroat	LM Bass	Pumpkinseed Sunfish	Sculpin
# Captured	14	19	5	3	2
Minimum Length (mm)	84	76	65	81	85
Median Length	98	108	76	81	--
Max Length	196	260	79	85	101

A number of spawning fish were observed in Des Moines Creek. Three spawning inventories occurred in late November and December, 1996 (Table 3.6), covering the park and plant reaches. Table 3.6 shows the number of live fish, fish carcasses and salmon redds ("nests") identified during these inventories. When possible, the sex of fish and carcasses was identified and is recorded. Pink salmon were also reported as being present in the park reach. While reported by a knowledgeable resident, these reports were not confirmed.

Table 3.6 Summary of Spawning Inventories in Des Moines Creek.

Date	Location	Species	Live Fish	Carcass	Redd
11/27/96	Park	coho		2M 1F	1
12/8/96	Park	chum	1F	2M	
		cutthroat	3		
12/20/96	Park	chum	13		3

M = Male F = Female

Physical Habitat

The physical habitat of Des Moines Creek has been inventoried several times in recent years. The most recent inventories occurred in August, 1986 (Johnson 1987), December, 1993 (Resource Planning et al., 1994), and for preparation of this report .

The 1986 inventory, which was primarily a qualitative inventory, described the stream as having little diversity in the first 0.4 miles of stream. It was most "natural" condition for the next 1.69 miles with abundant woody debris and a pool: riffle ratio of nearly one to one. In this reach, there were areas of exposed hardpan. Upstream of RM. 2.0 ((approximately South 200th Street - see Figure 1.2), the stream was channelized.

The 1993 inventory, which was more quantitative, collected data on the instream habitat and stream profile from the near the stream mouth to upstream to South 200th. This inventory found the most common habitat type was low gradient riffle. Of the 133 residual pool depths identified from the profile, the median residual pool depth was 0.9 feet. The dominant vegetative species in the riparian corridor were red alder, willows, and Himalayan blackberries. The substrate consisted of mostly 15 to 80 mm gravel.

In contrast to the “abundant woody debris” found in the 1986 inventory, there was only an average of seven to ten pieces of woody debris per 100 yards. Most of the woody debris was small and located along the edge of or suspended over the stream channel. Debris complexes were very limited.

In preparing this report, the inventory of existing fish habitat was updated in March-April, 1996. The fish habitat remains essentially low gradient riffles with a few lateral scour pools. The riparian vegetation consists primarily of young red alder with some Douglas-fir and western red cedar. Himalayan blackberry, salmonberry, vine maple and Indian plum are the dominate bankside vegetation. The stream substrate varies from silt and sand, small gravel, boulders, to large areas of exposed clay. Bank erosion and slope failures occurred in several areas throughout inventory reach. Similar to the 1993 inventory, most of the existing woody debris was small and located along the edges of channel or suspended over channel. The data from this inventory is contained in the Appendix.

Over the three inventories, the stream habitat has remained mostly shallow riffles with few pools. It appears that currently there may be less woody debris than existed in the earlier inventory . Also, it appears that the extent of exposed hardpan may be greater than in the 1986 inventory. Table 3.7 contains a summary of habitat impacts identified in the latest inventory.

Table 3.7 Summary Of Impacted Sites

River Mile FROM	TO	Impact Type	SITE DESCRIPTION
			PARK REACH
0.0	0.21	Habitat	Simplified riffle habitat.
0.21		Habitat	Wide-braided deposition zone downstream of Marine View Drive.
			TREATMENT PLANT REACH
0.38		Bank erosion	Road shoulder failure site.
0.62		Habitat	Large big leaf maple across channel, future flanking potential.
0.63		Bank erosion	Road shoulder failure site
0.58	0.64	Habitat	Wide-braided reach.
0.72	0.79	Habitat	Rock cascade, possible fish passage barrier.
0.75		Structural	Log weir, log is rotting.
0.80		Structural	Fishway, stop log needs to be replaced
0.91		Structural	Fishway, stop log needs to be replaced
			RAVINE REACH, Treatment plant to RM* 1.73
1.00		Bank erosion	Trail crossing is eroding the banks.
1.14	1.16	Slope failure	Large slope failure encroaching the channel. Channel width is reduced by 50 percent.
1.25	1.48	Bank erosion	Intermittent areas of right bank riprap failures.
1.38		Bank erosion	Road shoulder failure
1.39		Slope failure	Large right bank slope failure
1.45	1.49	Habitat	Clay substrate, sheet flows
1.67		Bank erosion	Road shoulder failure
1.68		Bank erosion	Downstream end of riprap, high flow back eddy eroding the bank.
1.73		Bank erosion	Right bank erosion, impacting the road and riprap
			PLATEAU REACH
1.93		Bank erosion	Narrow, deep, debris strewn channel, many partial debris jams.
1.97		Bank erosion	Braided reach with flanking erosion around debris jam.
2.06		Bank erosion	Numerous sites where high flows are flanking debris jams and eroding the banks.

* See Figure 1.2 for river mile locations.

3.6. Engineering/Public Infrastructure

Surface water engineering issues can be separated into several categories. “Drainage problems” are localized and affect only a small neighborhood or several properties and are related to components of the constructed drainage system such as pipes, ditches, or retention/detention (R/D) ponds. “Flooding problems” stem from streamflow exceeding the capacity of the stream channel and causing overbank flooding. Flooding problems affect a larger area and are more difficult to deal with than drainage problems, which can often be addressed through simple actions such as replacing a culvert. Another category of problems that merit consideration are problems related to “infrastructure”; this includes both the threat that erosive stream forces can pose to public works developments, and the effects such public works can have on the stream and its habitat. Data collection for this plan focused on identifying problems of all three types.

3.6.1. Flooding Problems

Regional flooding problems are uncommon in the Des Moines Creek drainage basin. In the upper basin, the stream and its tributaries are conveyed in drainage pipes and any problems tend to be of local scale. The lower stream corridor–at and below the Tyee Golf Course and South 200th Street–is buffered from human development. The park and ravine through which the stream flows has ensured that homes and businesses are not located adjacent to the stream, and there are very few road crossings.

The major flood problem in the basin is flooding of the senior center buildings in Des Moines Beach Park near the Des Moines Creek delta. An analysis of the flooding problems in this area was not prepared for this plan. The City of Des Moines has proposed removal of the senior center buildings from the floodplain, and analyses in this plan have assumed that this solution will take place in the near future. Past studies indicate that flooding of the senior center begins at approximately 175 cfs; this is about a two-year recurrence level under current land use conditions.

Flooding also occurs immediately downstream of the Northwest Ponds on Tyee Golf Course. Golf course operators have indicated that flooding occurs several times per winter, and modeling confirms that overflow from Northwest Ponds contributes to flooding on the golf course during events even more frequent than the 2-year storm. Low channel gradient and excessive plant growth in the channel also contribute to the flooding problems in this area. The major effect of this flooding is on golf course operations, as no public infrastructure or private or commercial buildings are threatened. A secondary effect of the flooding is related to the attractiveness of such areas to waterfowl. Given the proximity of Northwest Ponds to the south end of the SeaTac Airport, this bird use can interfere with commercial flights. The possibility of bird strikes is a safety concern to both the Federal Aviation Administration and the Port of Seattle. Future increases in impervious surface within the airport (upstream of Northwest Ponds) could increase the frequency, extent, and duration of flooding on the golf course property despite compliance with current stormwater regulations because current regulations do not fully mitigate the surface water impacts of development. However, the combined R/D and diversion recommendation for flow control under this plan could be designed to reduce the flooding frequency through the diversion of flood flows associated with small but frequent (more than once per winter) events.

3.6.2. Infrastructure Problems

Some problems are invariably created when public infrastructure such as roads and sewer lines intersect or run adjacent to the stream system. These problems can be caused by poor siting and location of the infrastructure or by maintenance activities associated with continuing operations. In some cases, the problems manifest themselves as threats to the infrastructure due to erosion or flooding caused by streamflow. In other cases, maintenance of the structures themselves creates problems for the aquatic habitat. In Des Moines Creek, these two occurrences are quite interrelated and create a challenge for continuing management of the system.

Road Flooding

There are very few crossings of the mainstem of Des Moines Creek: South 200th Street, two access bridges within the property of the Midway Sewer District treatment plant, Marine View Drive South, and two small bridges located within the boundaries of Des Moines Beach Park. Of these, only three -- South 200th Street, Marine View Drive South, and the park access road -- are public roadways meriting analysis in this plan.

With the exception of the access road bridge within Des Moines Beach Park, each of these structures is adequately sized to convey flows through at least the 25-year recurrence level under both current and future land use scenarios (the 25-year flow is the typical standard for arterial roadways). The access road bridge was significantly undersized and flooded frequently when this study started. This bridge was replaced during 1996 and the new structure is adequately sized to reduce the frequency of flooding problems being caused by the bridge to an acceptable level. Several crossings of smaller tributaries to Des Moines Creek create drainage problems, which are considered local and best handled by the individual jurisdictions.

Sewer Lines

There are two major sewer lines adjacent to Des Moines Creek: the outfall line for the Airport's Industrial Wastewater System (IWS) and the Midway Sewer District trunk line to, and outfall from, its treatment plant. Downstream of South 200th Street, these gravity lines run adjacent to each other on the west side of Des Moines Creek, under the service road. The IWS line is 18 inches in diameter for most of the alignment, while the Midway line is 24 inches. In most locations the two lines have identical inverts, with the Midway line located closer to the stream. An access road runs most of the length of the creek, both upstream and downstream from Marine View Drive South, directly on top of the sewer lines.

A major upgrade is underway for the Midway line, which is being replaced by an additional pipe with greater capacity (36 inches for most of its length). Construction of the new line is occurring during the summers of 1996 and 1997, with the existing line to be abandoned but remaining in place.

Because of the proximity of the sewer lines and access road to the main channel of Des Moines Creek, erosion of the access road has periodically occurred, including several areas of failure during the flood events of the winter of 1995-96. Past maintenance activities have consisted of placement of rock riprap along the bank of the access road, which is also the stream bank. This has resulted in a highly uniform channel with little variation in flow velocities and depths across the channel cross section, which has had adverse impacts on the salmonids that utilize Des Moines Creek. In response to the erosion events of 1995-96 and as an early-action project of this Basin Plan, the District repaired several sites of bank failure using biostabilization techniques during 1996. This entailed placement of a combination of large rock at the toe of the slope interlaced with root wads with attached stumps, with a vegetative matrix installed in the upper bank of the stream. The combination of wood and rock has resulted in greater channel complexity, protecting the bank while simultaneously providing shade, cover, and resting places for fish.

The five sites repaired in 1996 have localized habitat benefits, but they comprise less than three percent of the overall stream length impacted by the access road. The location and management of the road remains a significant issue for stream habitat in this system.

At the same time, the threat of high stream flows continues, and these flows and their erosive forces continue to create a potential problem for the sewer lines. Failure of the road and possible failure of one or both of the lines -- while unlikely given the high priority placed on maintenance -- would create a significant human health hazard and put the aquatic resources at greater risk. Such a failure would also require substantial public expenditure for repair.

Barriers to Fish Passage

The other significant impact of public infrastructure on the aquatic resources of the Des Moines Creek system is fish passage. A number of manmade structures across Des Moines Creek create complete or partial passage barriers. The most significant of these is the 4 x 6 foot box culvert under Marine View Drive South. At almost all flow conditions, velocities in this culvert are too high to allow fish passage. At low flows, shallow depths are a problem as well.

The gradient within the culvert varies, so that the upstream end is more steeply sloped than the downstream end. This has caused the downstream end of the culvert to collect sediment and gravel. Construction techniques may have led to a culvert without a uniform slope. During low flow conditions, velocities in the upstream portion of the culvert have been measured between 7 and 8 feet per second (fps). Calculations indicate that high flow velocities would be even greater at full flow. For a 225-foot long culvert, these velocities are all outside the necessary range for most fish to successfully migrate upstream.

A current interjurisdictional effort to replace the Marine View Drive culvert was begun in 1996, with preliminary engineering scheduled to be completed in mid 1997. This effort is focused on providing pedestrian access along the proposed streamside trail, providing a new sewer outfall line through the fill, and providing improved fish passage. Several sources of outside funding have been identified to assist in the replacement of the existing culvert including ISTEA funding, funding from the Midway Sewer District, possible grant funding from the Washington Department of Transportation, and cooperative funding from the jurisdictions sponsoring the basin plan.

A number of other barriers exist that are less important than the Marine View Drive culvert given their locations within the system (see Table 3.8). In addition, if the Marine View Drive problem can be resolved through the current proposal for pedestrian access, then these other barriers would become more important.

Table 3.8 Probable Barriers to Fish Passage in the Des Moines Creek System

Barrier Name	Location*	Remarks
Marine View Drive box culvert	RM 0.4	Appears to limit nearly all anadromous fish passage to entire Des Moines Creek basin. Proposed pedestrian access tunnel may solve problem
Midway Treatment Plant Log and Concrete Weirs	RM 0.9	Although designed for fish passage, weirs are likely barriers, at least at some flows
Concrete Weirs along Tyee Golf Course	RM 2.1	Three weirs (3 to 4 feet in height) render upstream passage impossible.

* See Figure 1.2 for river mile locations.

3.7. Problem Identification

One early phase of the Des Moines Creek Basin Plan involved the collection and assessment of existing information. The purpose of this work was to identify the existing surface water problems in the watershed through several mechanisms, including review of previously prepared reports, interviews with knowledgeable persons such as researchers and City staff, and through field assessments by team members. Information on the location, nature and likely solutions to the identified surface water problems were then collected and assembled into Table 3.9

Table 3.9 Initial Problem Identification

Reconnaissance Level Identification of Problems and Possible Solutions. This table documents initial efforts to identify problems and identify analysis needed. Please see Chapter 6 for final report recommendations.

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Water Quality	Basin-wide in mainstem Tribs in 1991-1992 were ok.	High Fecal Coliforms: -Storms (16,000-24,000/100ml) -Baseflow (1000->200/ 100ml)		Many possible sources: domestic animal waste, older septic systems, birds on ponds SKCDH-"known septic failures in unsewered and sewered (but not connected) areas-see map.	1) Conduct failure assessment in sewered & unsewered areas 2)Evaluate hookup strategies 3) Invest. sewer line expansion in unsewered areas inside UGB.	a,b,c, personal commun-ication
Water Quality	Outfalls; affects entire basin?	Periodic elevated BOD and ammonia.		Deicing and anti-icing events during storms?-(Glycol and potassium acetate). BOD =92 mg/l on 2/15/95		d
Water Quality	Throughout basin	White foam from unknown source.		Searches and sampling reveal no surfactants; needs further investigation	Look for illegal discharges; survey local land uses such as car washes, food establishments.	A. Johnson and G. Minton
Water Quality	Depends on location of spill	Episodic spills including petroleum, other chemicals from transportation accidents and local land uses		Airport has updated spill control plan. Tyee Pond serves spill control function for airport. Need plan for major roadways and cities.	Develop cooperative inter-jurisdictional spill response plan.	a
Erosion	Just above mouth	Localized erosion of the streambank has occurred just above the pedestrian bridge in Des Moines Beach Park	0.05	This will likely be fixed as an early action by the City of Des Moines.	Biostabilization: joint planting, rock toe w/ wrapped veg layer, or other	field, City of Des Moines
Sedimentation		Sediment deposition at delta	RM 0-0.1 (appx.)	Significance depends on evolving park development plans	Reduce sediment loads, primarily by reducing flows.	field

* See Figure 1.2 for river mile locations

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Habitat	Park reach	Simplified riffle habitat	0 - 0.21	Lack of habitat variability stresses fish due to lack of refuge areas such as pools.	Channel stabilization and habitat enhancement work.	field; detailed inventory by A. Johnson
Habitat		Fines in stream bed gravel	0 - 0.4	Moderate significance(depends on fish goals for delta reach).	Reduce fine sediment from construction activity & limit overall sediment loads, primarily by reducing flows.	field
Flooding	Just above mouth	Several buildings in the senior center in Des Moines Beach Park are frequently flooded. Park road and pedestrian bridge also flooded. Channel filling in from sediment. SU study suggests frequency of 1 to 2 yrs (175 cfs)	0.1	City proposing to remove buildings in near future. Access road will likely stay, given need for continued access to homes and for maintenance (expected to improve conveyance, perhaps to 100-year level). Consider possibility of major delta restoration.	Remove buildings or floodproof. R/D probably not cost-effective for flooding alone.	field, various studies (SU best), City of Des Moines
Erosion		Side-gully erosion --RB outfall, 6th S and S 218th	0.28	Low significance.	Extend culvert.	field
Erosion/ Drainage	Des Moines Memorial Drive	Experiencing small slides above and below roadway.	0.4		Stabilize. Divert erosive flows. Install energy dissipation.	City of Des Moines
Water Quality	Des Moines Memorial Drive	Possible water quality impacts due to vehicle traffic	0.4	City of Des Moines interested in incorporating BMPs into any conveyance upgrades.	Implement BMP program.	City of Des Moines
Fish Passage	Marine View Drive crossing	225-foot long box culvert blocks fish passage. High velocities even during low flow (8 fps at 10 cfs). Backwater (inlet control) during large flooding. Capacity flowing full around 200 cfs (2-yr event); however no overtopping threat due to height of embankment	0.4	City project proposed to construct a bridge to accommodate pedestrian trail use. Joint feasibility study with WSDOT, WSDFW, Midway Sewer underway.	Joint use tunnel or baffles or bypass pipe.	field, various studies

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Erosion	Along access road below treatment plant	Severe bank erosion in two locations resulting from Nov. 1995 flood; threatens sewer district access road	0.5-0.6	Midway Sewer District repaired in 1996 using biostabilization techniques, with Basin Committee technical support.	Biostabilization.	field, Midway Sewer District
Habitat	Marine View to Plant	wide-braided reach	0.58 - 0.64		Habitat improvements.	field; detailed inventory by A. Johnson
Erosion	Marine View to Plant	Maple tree blowdown could affect channel at future high flows	0.62		Not addressed.	field; detailed inventory by A. Johnson
Habitat	Marine View to Plant	Rock cascade, possible barrier?	0.72 - 0.79		Rework rock cascade to facilitate passage.	field; detailed inventory by A. Johnson
Fish Passage	Treatment plant	Concrete, rock, and log fish ladder structures may be hindering fish passage	0.9 - 1.0	Anadromous fish can't access this reach now, due to blockage at Marine View Drive. Will need to address issue once passage through Marine View Drive is established.	Major: remove struc-tures, rebuild stream w/ biostab. bank and grade control through rock & log fishway. Minor: retrofit by adding complexity w/small habitat elements (rocks, logs, etc.) Consider partial concrete demo.	field, Alan Johnson
Water Quality	Entire basin	Excessive periphyton growth and DO depletion. High nutrients (TP). Possibly fertilizer runoff from golf course, poorly operating septic systems	0.9	New concentration data needs to be checked for baseflow and stormflow; correlate w/ fecal data.	BMPs for golf course; reduce septic failures; N Side-gully erosion May be related to foam problem?	a,b
Erosion	Ravine Reach	Eroded trail crossing	1.00			field; detailed inventory by A. Johnson
Habitat	Ravine Reach	Sediment-free bed in ravine, clay substrate and lack of gravel	1.0-1.4 (appx.)	Moderate significance(depends on fish goals for ravine reach)	reduce flows, add energy dissipation	field; detailed inventory by A. Johnson

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Erosion	Along access road above treatment plant	Severe bank erosion in three locations resulting from Feb. 1996 flood; threatens sewer district access road	1.0-1.4	Midway Sewer District repaired in 1996 using biostabilization techniques, with Basin Committee technical assistance	biostabilization	field, Midway Sewer District
Erosion	Ravine Reach	Local bank erosion in ravine	Various 1.0-1.4 (appx.)	Significance depends on specific site and proximity to access road	Reduce upstream flows; armor and/or bioengineer sites	field; detailed inventory by A. Johnson
Erosion		Side-gully erosion --LB outfall, 14th S and S 212th	1.12	Low significance	extend culvert	field
Landslide	Ravine Reach	Large slide encroaching on channel. Channel width reduced 50%.	1.14 - 1.16			field; detailed inventory by A. Johnson
Erosion, Bank Failure	Ravine Reach	Intermittent areas where downstream ends of riprap sections are eroding	1.25 - 1.48			field; detailed inventory by A. Johnson
Erosion		Side-gully erosion	1.35	Low-moderate significance	disperse upland convey-ance in buyout area(s)	field
Erosion, Bank Failure	Ravine Reach	Downstream end of riprap wall, high flow back eddy eroded bank	1.68			field; detailed inventory by A. Johnson
Habitat	Plateau Reach	Narrow deep debris strewn channel. Many partial debris jams of complex woody debris	1.93			field; detailed inventory by A. Johnson
Habitat	Plateau Reach	Braided reach with flanking erosion around debris jam	1.97			field; detailed inventory by A. Johnson
Fish Passage	At and near South 200th St.	Concrete weirs up- and downstream of box culvert are a barrier to fish passage. Culvert capacity is adequate for at least 25-yr, probably 100-yr flow	2.1	Passage at 200th not considered significant due to limited anadromous fish habitat upstream. Weirs currently performing important water quality improvement function.		field; detailed inventory by A. Johnson
Hydrology	Tyee R/D Pond, golf course	Opportunity for more effective R/D through increased capacity in pond, and/or modified outlet	2.4	Current effect is flow reduction of 20 to 30% for most inflows. Tyee Pond would be eliminated is SASA were constructed.	Enlarge pond. Redesign outlet control works (different release rates). Regrade golf course.	Team, various studies, hydro analysis

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Water Quality	Upstream of 200th- culvert	High Metal Concentrations: -Zn and Cu exceed federal and state acute and chronic standards -Cu exceeds federal acute and chronic standards		Urban runoff including airport runoff; ubiquitous road runoff.	increase TSS removal in r/d ponds; install biofilters; increase r/d on road/highway projects; drain stenciling; public awareness programs.	cc
Drainage/ Flooding/ Water Quality	7th Ave. S, south of S 216th St.	Sheet flow across commercial properties causing localized flooding. May be water quality issue as well, as commercial use includes auto repair, etc.		Does not appear to significantly impact stream.		City of Des Moines
Drainage/ Flooding	Tyee Golf Course	Golf course experiences flooding on thirteenth hole, differential settling problems due to peat soils. Low velocities creating water temperature and dissolved oxygen problems.	Trib. #0379, RM 0.2	Moore suggests regrading to improve slope between outlet of NW ponds and confluence with tributary # 0377.	Regrade to increase slope, detention downstream.	field, Tyee course management
Drainage/ Flooding	S 188th St. (west of tunnel)	Flood problems along the roadway have been increasing in frequency, which City of SeaTac suggests may be related to Port development. Roadway lanes have required closure several times, including in Feb. 1996				City of SeaTac
Drainage/ Flooding	S 188th St. And 28th Ave. S (downstream of Red Lion parking lot)	Undersized pipe system causes flooding at low point of 28th Ave. S (don't know frequency; appears to be local problem)	3.4	60" line (part of system from Bow Lake outlet) downsizes into smaller pipe. Barrett Engineering is studying this.	SeaTac will likely replace w/ larger pipe.	City of SeaTac

Problem	Location	Description	RM*	Comments/ Status	Alternative Solutions	Sources
Hydrology	Bow Lake	Inadequate storage/detention in upper basin	3.5 Trib	Sea-Tac considering regulation of Bow Lake to increase active flood storage. Regulation of lake could entail construction of a 12" line with a valve that would provide secondary lake outlet when open (pipe would lead to old, under-utilized 3'x5' box) This is part of study by Barrett Engr.		City of SeaTac
Drainage/ Flooding	S 204th St.	Road and trailer park flooded by small trib (don't know frequency; appears to be local problem)	Trib 0377A, RM 0.1	Produces no significant impact to stream due to buffering by large wetland.		City of SeaTac
Drainage/ Flooding	Executel Pond at S 208th St.	Pond breached in 1990; embankment may have seepage problems.	Trib 0377A, RM 0.5	Pond's detention effect is minimal, less than 10% for most flows	Stabilize embankment, remove pond (replace storage elsewhere). Enlarge outlet structure	City of SeaTac

a) “City of Des Moines Water Quality Monitoring Program- 1995 Annual report,” City of Des Moines, October 1995

b) “Des Moines Creek Problems/Solution Assessment”, Port of Seattle, July 1995

c) “Des Moines Creek Water Quality Study”, Port of Seattle, March 1992. (From “South Aviation Support Area Report, Technical Appendices”, Port of Seattle, March 1994, Appendix D)

3.8 Problem Prioritization

One of the tasks specifically called out in the Des Moines Creek Scope of Work was the prioritization of identified problems, and the separation of the problems into a list of “regional problems” and a list of “local problems”. Regional problems are generally those which involve more than one jurisdiction, or which impact the overall health of the stream. Local problems, on the other hand, are those which impact only one jurisdiction and only a small isolated portion of the watershed. Local problems also have relatively minor environmental impacts when viewed on a watershed scale, and are not expected to impact the overall health of the creek's aquatic ecosystem.

The initial step in this prioritization process was the identification of possible problems. The project team performed field reconnaissance trips throughout the basin, reviewed existing studies and reports, and met with knowledgeable individuals such as public works and sewer district employees to identify and characterize as many potential problems as possible. Once a complete listing of known problems was created, the project team then sorted the listing into a list of local problems and a list of regional problems based on the criteria discussed above.

To prioritize the identified problems on the regional and local problem lists, a simple rating system using a series of criteria was prepared. A brief description of the criteria is given below:

Significance/Impact to System: For a stream system to work, a number of physical and biological forces must be roughly in balance. Some problems pose a much greater risk to this balance than others. The environmental significance of the problem to the overall health of the stream system was used as a key criteria. Zero points for a problem with little significance, 50 points for a problem which definitely impacts the system, and 100 points for a problem with the capacity to undermine the health of the system.

Affects Basin Committee Goal Attainment: This Basin Plan was prepared specifically to address the goals of the Basin Committee (see Executive Summary). Problems which interfere with the ability of the Committee to attain these stated goals are of higher priority than problems which do not interfere with accomplishing these goals. Zero points for problems which do not interfere with goal attainment, 50 points for those which produce some interference, and 100 points for problems which seriously interfere with attainment of the Committee's formal goals.

Threatens Significant Infrastructure: Several substantial investments in infrastructure already exist within the basin and are potentially impacted by the stream system, most notably the sewer and Industrial Wastewater System pipelines along the stream, the several bridges and culverts along the stream, and the Senior Center buildings in Des Moines Creek Park. Zero points if the problem does not threaten infrastructure, 50 points if there is some level of threat, and 100 points if there is a definite and substantial threat to a significant piece of infrastructure.

3.8.1. Prioritization Process

The first steps in this process are described above and involved the identification and characterization of the problems and the assignment of individual problems to the regional or local listing. The project team, which has knowledge of the stream system and the individual problems, then rated the problems using the criteria described above to develop a numerically ranking for the problems. This numerical ranking was then used to assign problems to the High, Moderate or Low Priority categories.

Ranking Category	**Points**
Regional - High Priority	125-200
Regional - Moderate Priority	75-124
Regional - Low Priority	<75
Local	0-200

The prioritized list was reviewed and approved by the Project Management Team and subsequently used as the listing of problems which the technical team focused on during development of the integrated strategy for watershed management in the Des Moines Creek basin (see Table 3.10).

It should be noted that this listing and prioritization of problems served only as the starting point for the development of solutions. Some of the problems on this listing have been addressed by the individual jurisdictions and are no longer an issue. Some of the problems are symptoms of the larger stream issues which are addressed by the proposed regional facility. The Project Management Team chose to focus on resolving systemic stream issues and creating a viable stream system rather than responding to a “punch list” of problems previously identified.

Table 3.10 Initial Problem Prioritization for Des Moines Creek Basin

	Problem	Significance - Impact to System (0,25,50,75, 100)	Affects Basin Committee Goal Attainment (0,25,50,75, 100)	Threatens Significant Infrastructure (0,25,50,75, 100)	Total
Regional High Priority	Fish passage blocked at Marine View Drive	75	100	25	200
	Flooding in Des Moines Park	25	75	75	175
	High temperatures and low flows during summer	100	75	0	175
	Too much riffle habitat, not enough pools	100	75	0	175
	No gravel in streambed in ravine	100	75	0	175
	Severe bank erosion at 2 locations below sewer plant	50	50	75	175
	Episodic spills	75	75	0	150
	Tyee Golf course temperature and flooding	75	50	0	125
	Tyee Pond outlet improvements	50	50	25	125
	Fine sediment in gravel, at Beach Park	50	75	0	125
	Large slide in ravine	50	25	50	125
	High fecal coliform levels	25	100	0	125
	Periodic elevated levels of BOD and ammonia	75	50	0	125
Regional Moderate Priority	Debris jams on plateau reach	75	25	0	100
	Fish passage at sewer plant ineffective	50	25	25	100
	Rock cascade creating possible fish blockage	50	25	0	75
	Intermittent erosion of rip-rap sections	25	25	25	75
	White foam from unknown source	50	25	0	75
	Severe bank erosion at 3 places in ravine	25	25	25	75
	Local bank erosion in ravine	25	25	25	75
	Sediment deposition in delta	25	25	25	75
Regional Low Priority	Excessive braiding of channel below sewer plant	25	25	0	50
	Bow Lake storage outlet improvements	25	25	0	50
	Slides above and below Marine View Drive	25	0	25	50
	High metal concentrations in water	50	0	0	50
	Downed trees below sewer plant	25	0	0	25
	Concrete weirs creating fish blockage on golf course	25	0	0	25
	Eroded trail crossing in ravine	25	0	0	25
	Braided reach w/ flanking erosion around debris jams	25	0	25	25
Local	Executel Pond seepage problems	50	25	75	150
	Trailer park and road flooding	0	25	75	150
	Stream bank erosion in Des Moines Beach Park	25	25	25	75
	Water quality impacts from road runoff	50	25	0	75
	Undersized pipe causing flooding on 28th Ave S.	0	0	25	25
	Sheet flow flooding near 7th S. and S. 216th	0	0	25	25
	Flooding on S. 188th	0	0	25	25
	Side gully erosion at RM 1.35	25	0	0	25
	Side gully erosion at RM 0.28	25	0	0	25
	Side gully erosion at RM 1.12	25	0	0	25

3.9. Future Problems

3.9.1. Land Use Trends

Approximately 35 percent of the Des Moines Creek basin is currently covered with impervious surfaces that contribute stormwater directly to drainage system of the creek. This large percentage of impervious area within the basin is causing elevated flow levels following storms, accelerated levels of erosion and sedimentation, aquatic habitat degradation, and elevated levels of pollutants which degrade water quality.

Under future conditions approximately 46 percent of the Des Moines Creek basin is expected to become impervious area, an increase of one/third above current conditions. About one-half of this increase in impervious area will occur as residential and other small land use changes located within the cities. Development within the cities is expected to raise the overall impervious area within the basin from 35 to 47 percent of basin area.

The three large projects under consideration in the basin will account for the conversion of an additional 6 percent of basin area to impervious cover. These projects include the proposed 3rd Runway at SeaTac International Airport, the South Aviation Support Area, and the extension of State Route 509. The 3rd Runway and SASA are each expected to raise overall impervious area about 1.75 percent each, and the State Route 509 extension is expected to raise overall impervious area 2.4 percent.

3.9.2. Geology Trends

Given the characteristics of the regional geology and the magnitude of existing development, future conditions in the Des Moines Creek channel would differ from the present only by degree, even if none of the recommended management actions are taken. Erosion downstream of South 200th Street would cause problems for the sewer line at progressively more sites, individual bank-repair projects would have a shorter lifetime, and the average interval between initial failure and potential undermining of the road or pipeline would shorten as the frequency and intensity of sediment transport increased. In time, one major change in behavior of the channel might be anticipated: accelerated infilling of the lowermost channel, in the Beach Park reach, could result in semi-annual flooding of the lower park area and a potential shift from a single-thread to a braided channel, with attendant loss of channel stability and impeded low-flow fish passage.

3.9.3. Hydrology Trends

The future stream flow regime will be determined by the amount of new development and corresponding impervious surface area coupled with the stormwater control measures installed by future development (See Section 5). According to current zoning and plans for future major infrastructure projects, current effective impervious area may increase by as much as 58 percent at basin buildout. If current standard detention pond design guidelines (King County, 1990) are utilized in the construction of new projects within the basin, peak annual discharges in the mainstem and its tributaries should not increase significantly. However, these standard ponds are not likely to arrest increases in stream flow erosivity caused by increased duration of high flows; nor will they mitigate the decrease in stream base flows that generally accompanies land development. Additional non-standard stormwater control measures would be required to prevent these negative impacts to the stream flow regime.

3.9.4. Water Quality

Since water quality conditions are linked to land use, further degradation can be expected in Des Moines Creek as the basin develops, unless water quality controls and treatment are employed. Two management strategies are feasible: source control through implementation of best management practices and water quality treatment through constructed facilities.

Several state and King County ordinances require source control through best management practices (i.e., NPDES, King County Water Quality Ordinance) for selected land uses. The Port of Seattle has an NPDES stormwater permit for the airport and discharge of pollutants from the airport is controlled by the permit conditions established by the WSDOE. The Cities of SeaTac and Des Moines are below the population thresholds requiring NPDES stormwater permits.

It is important to point out that existing roadways and single family residences, well-known sources of chronic pollution, are not required by law to implement source controls. Unfortunately, the loadings from these sources are diffuse and difficult to manage and are directly influenced by the size and lifestyle of the population in the Des Moines Creek basin. For existing roads, improved road maintenance techniques and retrofitting road drainage systems as roadways are modified can improve water quality. However, contamination from road runoff is directly related to traffic levels, so as traffic increases, water quality pollution from roads is also expected to increase. As this area develops, the increase in traffic will be responsible for an increasing portion of metals loading. Washington state law requires that newly constructed state highways and roadways provide runoff controls. Water quality of road runoff could be improved by designing surface water systems of new roads to accommodate storm flows from existing road surfaces.

Fecal coliform concentrations, which are currently of concern, can be expected to continue as a concern unless actions are taken to investigate and reduce sources. The WSDOE believes that Des Moines Creek does not meet fecal coliform standards now and has placed the stream on its 303(d) list of “troubled waters”. In the future, that agency may require a comprehensive management plan under the Federal Clean Water Act to reduce fecal coliform loadings to the creek. The identified presence of fecal coliform in this study suggests the advisability of some future action here (such as locating and reducing sources) to help correct this widespread problem, otherwise it is highly likely this problem will get worse.

3.9.5. Engineering/Infrastructure Trends

While the projected land use changes will result in increased flows through Des Moines Creek and its tributaries, this flow increase is not expected to result in new flooding problems. Most importantly, the major road crossings of Des Moines Creek will continue to have sufficient capacity for the future 25-year flow.

With future land use changes, existing problems would be worsened slightly, in terms of both magnitude and frequency of their occurrence. If not removed, the buildings in Des Moines Beach Park will continue to experience flood problems at a greater than two-year frequency. In addition, construction of the joint use tunnel under Marine View Drive South will remove some upstream storage from the Des Moines Creek system, which could be expected to worsen conditions at the senior center. However, it is important to recognize that storage behind the road fill at the existing culvert becomes effective only in excess of flows of 175 cfs. Thus, enlargement of the culvert would not substantially alter the frequency of flooding of the senior center. If the culvert is upgraded, then water surface elevations of larger flood flows (5-year frequency and above) would be marginally greater at the site of the senior center than with the current culvert in place.

If unchecked through mitigation or regional solutions, the stream flows resulting from future land use changes would continue to destabilize the Des Moines Creek ravine, resulting in a continuing threat to the Midway sewer line and the need for ongoing maintenance. The frequency and annual magnitude of this maintenance need would be expected to increase.

3.9.6. Fisheries Trends

The flow regime of Des Moines Creek (i.e., both high and low flows) and the simplified habitat are likely the principal factors currently limiting salmonid production in the stream. In spite of these major limitations, a small but healthy population of fish exists throughout all reaches of the stream with the possible exceptions of the East and West Forks, on the Tyee Golf Course. If no action were taken to increase the amount or quality of the available habitat, presumably the same small numbers of fish would continue to reside in the creek.

If the volume of storm flows continue (i.e., are not reduced nor increased), the streambed scour observed in the lower reaches of the creek will likely continue. Expected increases in duration of elevated stream flows following storms, caused by increased impervious area within the basin, will increase scour and erosion. Similar to the comments above, while the existing streambed scour is limiting, fish populations will likely continue at existing numbers.

Several barriers to fish passage have been identified in various studies. If these barriers are not removed (in particular, the box culvert under Marine View Drive South), they will continue to limit the use of upstream habitat, especially by anadromous fish. The populations of resident fish are likely to be less affected by these barriers.

The full influence of the existing water quality on fish populations is not known. Elevated water temperatures, which are limited to reaches upstream of South 200th Street, do not appear to be limiting fish populations in this reach. Episodic events such as toxic spills will continue to threaten fish.

4. DEVELOPMENT OF PRELIMINARY SOLUTIONS

4.1. Overall Stream Health as a Primary Policy Choice

4.1.1. Policy Choice: Level of General Stream Health

The project team initially developed a wide range of possible future scenarios for the creek. This range of future scenarios was designed to encompass all reasonably attainable outcomes for the creek and to help clarify the policy choices facing the jurisdictions within the Des Moines Creek basin.

The initial Scope of Work, and subsequent discussions with the Project Management Team, made it clear that the principal measure of success for the basin plan was the overall ecological health of the stream, manifested primarily in the fish populations supported by the creek. With this in mind, the technical team developed the following generalized scenarios for the future of Des Moines Creek.

All four scenarios presume the same level of new land-use development within the basin. In order to make sure that the analysis provided a conservative answer (i.e., one that left a safety margin for the stream) it was assumed that all currently proposed changes within the basin would occur. Within cities this meant that all areas were developed at the maximum densities allowed under their current comprehensive plans. Changes in land use within the cities will produce about 440 acres of new impervious area during the 10- to 20- year period covered by existing Comprehensive Plans.

Major projects within the basin were assumed to proceed and included the extension of Washington State Route 509, construction of the South Aviation Support Area (SASA), and construction of the 3rd Runway. All major projects were assumed to meet existing mitigation requirements relating to surface water, unless additional mitigation was suggested in project documents. It should be noted that these major projects all impact the creek hydrologically to about the same extent, and taken together the three projects produce less than half the change in impervious area that land use changes within the cities are expected to produce. The extension of State Route 509 is expected to produce 87 acres of new impervious area; the South Aircraft Support Area (SASA) is expected to produce 67 acres of new impervious area; and the 3rd Runway is expected to produce 67 acres of new impervious.

Should any of these projects fail to proceed, some additional margin of safety would be provided to the stream. All of these large projects occur in the vicinity of the stream and could, through poor construction practices or inadequate erosion/sedimentation control measures, produce significant impacts to the stream.

The proposed land use changes within the basin reinforce existing trends of degradation due to changes in streamflow. Indeed, hydrologic problems dominate the future of Des Moines Creek. Future levels of erosion and sedimentation are driven by hydrology, and habitat stability is driven by future erosion. The project team concluded that in the absence of improved flow control, improvements to habitat and water quality would produce, at best, a short-term improvement before they were overwhelmed by hydrologic changes.

Each of the following scenarios reflects a different level of future stream health, and in turn implies a different set of challenges which the jurisdictions would face in reaching the future described in the scenario. The following set of generalized scenarios was developed to help clarify the policy choice facing the jurisdictions.

4.1.2. No Action: Ongoing Degradation of Stream Flow Regime

This scenario would involve taking no specific actions for protection or enhancement of creek health. Existing surface water management regulations would continue to be enforced and no regional surface water management projects would be constructed.

Under this alternative, existing trends in stream ecological processes would continue. There would be a continued increase in the frequency of bank failures and erosion events in high energy areas of the stream system, particularly in the ravine between the sewer plant and South 200th Street. Bank repairs would be a combination of bio-engineering (where feasible) and traditional bank armoring.

Trends in stream flows would continue. The frequency and duration of high stream flows would increase over existing conditions, causing additional erosion problems and resultant habitat degradation. Summer stream flow levels would continue to decrease, bringing significant stress events to fish populations during the warmer months.

Fish populations would be expected to face substantial difficulty in surviving, although remnant populations might be able to survive for some time. Continued loss of habitat, disturbances related to increasingly frequent infrastructure repairs, high winter flows, low summer flows, and sedimentation of gravel would continue to reduce the remaining fish population, potentially eliminating them. Due to the poor hydrologic regime, habitat improvement projects would not be worthwhile since high flows would likely destroy them after construction.

4.1.3. Alternative: Slow Rate of Degrading Flow Regime

This scenario would focus on slowing the rate of degradation in stream flow conditions. To achieve this level of protection, some additional effort would need to be taken by the jurisdictions. This effort could involve construction of regional surface water facilities, or a combination of new facilities and increased regulatory control over on-site surface water detention required of new development.

In this scenario, efforts would be made to slow the rate of degradation of existing stream ecological processes. Bank failures and erosion events in high energy areas of the stream system would continue at approximately the same frequency as is currently occurring. Bank repairs would be a combination of bio-engineering (where feasible) and traditional bank armoring.

Negative trends in stream flows would be slowed, with stream flows and durations degrading more slowly than the No-Action alternative. High winter flows and low summer flows would continue to stress fish and benthic invertebrates, and limit overall population sizes.

Fish populations would continue to decline over time, but at a slower rate than would occur in the “No Action” alternative. Some short term habitat improvements could be made, such as riparian-zone revegetation or installation of in-stream habitat structures, but these would be eventually overwhelmed by continued impacts of high flows, necessitating more frequent maintenance of habitat features.

4.1.4. Alternative: Stop Degradation of Flow Regime

This scenario would stop the existing negative trend in stream health. In order to counteract the negative impacts of both existing and proposed new development within the basin, significant regional surface water management facilities would need to be constructed. Additional regulatory control could be substituted for some of the regional facilities but would not be sufficient, in itself, to change the current negative trend to a positive trend.

In this scenario regional detention facilities would be constructed in the vicinity of the golf course and would provide increased control over most winter storm flows. Reduction in peak storm flow duration would stabilize erosion rates at current levels in the mainstem below South 200th Street. Stabilizing erosion rates would result in a more stable physical environment, allowing a program of habitat improvement projects to be implemented. Energy dissipation structures, to limit erosion and sedimentation in the ravine reach, would be installed. Habitat projects would include such activities as replanting of stream banks, creation of channel meanders, installation of large rocks, and installation of large woody debris. Habitat improvements would be limited to the area downstream of the sewer plant. The largest project would involve establishing fish passage past the Marine View Drive culvert.

Reductions in erosive flows and creation of additional in-stream habitat structures would provide additional habitat, and would be expected to support increased fish populations. This flow regime would not produce a stable physical environment, as erosion rates would continue at current levels and periodic human intervention would still be needed to stabilize banks, replace damaged habitat features, and maintain the existing access road.

4.1.5. Alternative: Achieve Stable Flow Regime

This scenario would seek to reverse the trend of slow degradation by improving flow conditions and establishing a healthier stream system than is in place today. To accomplish this, significant regional surface water management facilities would need to be constructed to control high stream flows. Flow volumes needing control are sufficiently large that changes in surface water management regulations or construction of new detention facilities alone would not be effective at mitigating damages to the level needed for this scenario to be realized.

During preliminary analysis, several possible projects were identified which attempted to attain the "stable stream system" goal. Project alternatives considered included establishment of regional detention facilities, construction of a large bypass pipe, and changes to regulations. These possible projects vary widely in their success at reaching the "stable flow regime" goal, had a broad range of costs, and presented some significant engineering or permitting challenges. These project alternatives are discussed in the following chapter.

The large reduction in storm flows this alternative would produce would also substantially reduce erosion rates and bank failures in the mainstem below South 200th Street. Substantially reduced erosion rates would result in a more stable physical environment, which in turn would allow a series of habitat restoration and habitat creation projects to be implemented successfully in the area below South 200th Street. The largest habitat related project would involve restoring fish passage past the Marine View Drive culvert. Other habitat projects would include such activities as replanting of stream banks, creation of channel meanders, installation of large rocks, and installation of large woody debris. Habitat restoration efforts above the sewer plant would concentrate on adding structure and reducing erosion in the ravine reach, primarily to help rebuild the gravel supply in the stream bed. Substantial reductions in erosive flows and significant creation of additional in-stream habitat structure would be expected to support much larger fish populations than currently exist.

4.2. Available Tools

The primary cause of changes in flow regime of an urbanized stream system is the increased runoff rates which result from conversion of forest and other natural land covers into impervious areas such as roofs and roads. Changes in flow peaks, and in the duration of elevated flow levels, following rainfall events both produce undesirable impacts in the stream corridor. The first step in addressing the physical problems of the watershed is to return stream flows to a more natural, and less damaging, regime. There are a limited number of tools, described below, available to help address the problems with stream flows which urbanization produces in watersheds.

4.2.1 Regulation

One method for lessening the impact of increased stream flows is to require new development to mitigate for impacts which it causes. This method has been widely adopted, with jurisdictions throughout the region requiring new development to comply with either the King County or the Washington State drainage manuals. The typical mitigation required is to construct a retention/detention facility which holds water back during a storm event and then meters it out slowly over the following several days.

Since the Des Moines Creek basin already has substantial deficiencies in the volume of detention available, and since current regulations do not fully mitigate for flow impacts caused by development, the current regulations will not be sufficient to provide the amount of detention the basin needs in order to establish a stable stream system, either now or in the future.

One response which has been used in King County on several instances in the past is to make the detention requirements for new development more strict by requiring additional on-site detention volumes. This strategy directly reduces the amount of land to be developed on any particular lot since larger detention ponds are required. Questions of equity between current and past development occur with this strategy, since new development is required to do much more mitigation than development which occurred in the past. There are also difficulties in administering this strategy if the individual jurisdictions wind up with more than one level of detention requirement.

4.2.2. Land Use Changes

Change in allowable land use is another method for addressing the projected increases in surface water runoff attributable to development. By reducing the density of development allowed by zoning the amount of forest clearing and impervious area can be affected. This method is usually referred to as "down-zoning" and is most effective in rural areas where development has not yet converted large areas of forest into urban land uses. Specific changes to zoning codes covering clearing and lot coverage can also accomplish similar outcomes, again with the greatest effectiveness in rural areas where conversion from forest has not already occurred. The overall reduction in future land use development has a direct effect on the amount of impervious area which would be created, which in turn reduces the magnitude of future flow impacts.

An alternative approach is to reduce impervious surfaces through site design. Examples include narrower roads within the development; hammer-head rather than circular cul-de-sacs; open blocks instead of pavement in low-use parking areas; and having roof leads drain to grass and vegetated areas rather than directly to the storm drain system. The City of Olympia has conducted several studies on this approach (City of Olympia, 1996), as has the City of Portland, Oregon.

4.2.3. Regional Detention/Sites Previously Considered

Creation of additional detention facilities is a third tool that can be utilized in protecting streams from the impacts of nearby humans. Development, even under current regulatory requirements, does not fully mitigate for its surface water impacts. Creation of regional detention ponds can mitigate for past impacts, and for future unmitigated flow impacts in a manner similar to that performed by the lot-by-lot detention ponds discussed in the preceding section on "Regulations". Regional detention ponds are often difficult to site since they require large land areas and they must be located in an advantageous position within the basin in order to perform their function properly.

Several previous studies have identified potential sites for locating additional retention/detention facilities within the Des Moines Creek Watershed. The 1995 Seattle University study (Des Moines Creek Detention Facility Site Assessment) was the most recent, and focused on identifying and investigating a series of potential sites throughout the watershed. Nine sites were examined by the Seattle University study, with four being eliminated from further consideration. The five which were studied further included Northwest Ponds, an in-stream site just upstream of Marine View Drive, the large wetland just south of South 200th Street, an infiltration site just south of the wetland, the proposed SeaTac Business Park drainage facility, and Tyee Pond (on the Tyee Golf Course). Each of these potential sites was re-examined in this effort to determine its' potential to help address detention needs in the Des Moines Creek watershed, both under current conditions and under the projected future conditions which the watershed will face. Several of the remaining sites were eliminated from further consideration at this stage.

The proposed in-stream site on the upstream side of Marine View Drive would provide little useful attenuation of flooding impacts, and would need to be located on the best remaining salmonid habitat in the watershed. With the scheduled replacement of the Marine View Drive culvert to allow fish passage and the planned removal of the Des Moines Senior Center, this site was judged to be ineffective at meeting the goals of the Basin Committee. The large wetland site south of South 200th Street was also eliminated from further consideration at this stage due to concerns over eliminating the existing water quality function of this wetland, concerns over construction difficulties associated with poor soil conditions in the area, and anticipated regulatory issues associated with use of a large forested wetland for detention. The proposed infiltration site was not examined further due to concerns with infiltrating water at the head of the ravine, and due to lack of ready acceptance of this technology by the engineering community.

The remaining sites are all located on or adjacent to the existing Tyee Golf Course. Sites in the vicinity of the golf course proved to be especially attractive for regional detention purposes for several reasons. The golf course is located in a particularly advantageous position for regional detention purposes. Both major tributaries are located on the golf course, potentially allowing all of the upper basin flows to be controlled by a single facility. Golf course sites are potentially large enough that all of the regional detention needs of the watershed could be met with a single facility, avoiding the necessity of constructing and maintaining a series of smaller facilities. The golf course sites also currently have diminished fish and wildlife values due to low stream flows, poor water quality, and minimal stream buffers. Construction of a new detention facility would allow improvements to water quality, flow rates and stream buffers.

Finally, portions of the golf course currently flood regularly limiting use of the golf course and creating a potential safety issue. Safety issues result from the potential attraction of waterfowl, other large birds and flocking passerine birds to the flooded golf course which lies directly under the flight path of Sea-Tac International Airport. The FAA is particularly concerned with the potential for waterfowl to be ingested by jet engines during critical take-off and landing phases, when loss of power due to a failed engine would be particularly troublesome. Damage to windshields, and communication and navigation equipment from bird strikes is also a concern. Golf course sites present the opportunity to address existing safety, flooding water quality and habitat issues as part of facility construction.

4.2.4. Bypass Pipe

Another method for addressing flow increases in stream systems is to create a "high-flow bypass" pipe. This involves creation of a diversion structure in the stream which lets normal flows pass through, but which diverts larger flows into a pipe (the bypass pipe) which carries the damaging flows around the sensitive portion of the stream channel. Engineering and construction of bypass pipes can be challenging since minor changes in the diversion structure can easily divert too much water (damaging the stream's health with low flows) or too little water (damaging the stream's health with the same large flows the pipe was constructed to address). Sizing of the bypass pipe can also be critical since it must be sufficiently large to accommodate anticipate future flows, but small enough that it is affordable and can be constructed. Siting of bypass pipes in heavily urbanized systems like Des Moines Creek is also a significant challenge since there are few locations where a four to six foot pipe could be installed. Bypass pipes are often routed so that once water enters the pipe, it does not return to the stream. In Des Moines Creek, a bypass pipe would be most effective by discharging directly into Puget Sound.

4.2.5. Combinations

Each of the surface water management tools described above (regulation, land use changes, detention, bypass) have situations in which they are very effective, and situations where they are not very effective or where they are exorbitantly expensive. Each of these tools can also be used independently of the others. In practice most surface water management programs use combinations of several of these tools, chosen specifically for each watershed based on the effectiveness and cost of implementing each strategy.

In Des Moines Creek, many of the land use changes have already been made through the Comprehensive Plan process. Little opportunity is believed to exist for altering the future land uses over any significant portion of the basin. Regulatory changes are also expected to be ineffective in the Des Moines Creek watershed, primarily due to the difficulty in administering a separate set of regulations for only that portion of the jurisdiction located within the Des Moines Creek drainage. Regulatory changes also bring significant political challenges to effective implementation due to additional administrative costs, equity questions between new and existing development. This leaves physical changes to the system, such as a bypass pipe, creation of regional detention facilities, or some combination of strategies as the most effective and affordable tools for addressing the surface water management needs of Des Moines Creek.

4.3 Preliminary Analysis

Each of the generalized scenarios described in Table 4.1 was evaluated to determine which tools would be effective in reaching these different levels of stream stability. This was done in an attempt to identify if any of these different levels of stream stability were unobtainable, if any of these alternatives were prohibitively expensive, or if any were obviously an appropriate choice. The following information summarizes the project choices and the planning-level estimates of the effectiveness and costs of each alternative. Table 4.1 summarizes the policy options and the various construction alternatives possible under each policy option.

4.3.1. No Action: Ongoing Degradation of Stream Flow Regime

The No Action scenario proposes no change in current policy or surface water management regulations, and no construction of regional facilities. On-site detention controls for new development would be the same as is currently required through drainage regulations. No new discrete costs would occur, with all costs hidden as cumulative environmental damages.

4.3.2. Slow Rate of Degrading Flow Regime

Slowing the rate of degradation in the stream flow regime in Des Moines Creek appears to be attainable using any of four alternatives. Each presents political difficulties and technical challenges. Slowing the rate of degradation in the current flow regime provides no increase in the level of stream health.

No instream or riparian habitat improvement projects are proposed under this alternative since continued increases in flow levels are anticipated to cause increasing erosion and bank stability problems. Habitat improvements in a degrading flow regime such as this would have a limited life span before they were in turn damaged by erosion, and were considered a poor investment. Should habitat improvement be desired and the risk of project failures be deemed acceptable, projects similar to those proposed in the next section could be added.

One alternative is to construct two regional detention facilities in the vicinity of the golf course, providing approximately 260 acre-feet of flood storage. The planning-level estimate for this proposal is $8M ($4M for each pond).

A second alternative is to construct smaller detention facilities (approximately 120 acre-feet of storage) and to modify existing surface water regulations to require a higher level of on-site surface water detention than is currently required (approximately 3 times the volume as currently required) on all new development in the watershed. The planning-level estimate for a new detention pond is $3M. Estimates for the cost of new regulation are expected to be a non-trivial cost to the jurisdictions (for such things as administrative and training costs, and for slower increase in tax base when development occurs elsewhere), and are estimated to be approximately $15 - $20 M. to the development community (for such things as added construction and land costs).

A third alternative is to construct a smaller regional detention facility (approximately 120 acre-feet) and to utilize the (soon-to-be) abandoned 24" Midway Sewer District pipeline to provide a moderate level of high flow bypass for the area below South 200th Street. While this would provide a relatively small level of flow reduction, it would bring most storm flows below the erosive threshold. Planning-level estimate for new detention pond is $3M. Planning level cost estimate for using the abandoned 24" sewer line as a bypass pipe is approximately $700,000, presuming the abandoned pipeline was attained at no cost. Costs would include installation of additional piping for the portion of the sewer alignment not being abandoned, and construction of a diversion facility to capture high flows and route them to the pipe.

A fourth alternative is to modify existing surface water regulations to require a higher level of on-site surface water detention than is currently required (approximately 3 times the volume), and to utilize the (about to be) abandoned 24" sewer pipeline to provide a moderate level of high flow bypass for the area below South 200th Street. While this would provide a relatively small level of flow reduction, it would bring most storm flows below the erosive threshold and provide some level of habitat protection. Large storm flows would continue to produce substantial changes to the stream system. Estimates for the cost of new regulation are expected to be a non-trivial cost to the jurisdictions (for such things as administrative and training costs, and for slower increase in tax base when development occurs elsewhere), and are estimated to be approximately $15 - 20M to the development community (for such things as added construction and land cost). Planning-level cost estimate for the small bypass alternative is approximately $700,000, presuming the abandoned pipeline was attained at no cost. Costs would include installation of additional piping for the portion of the sewer alignment not being abandoned, and construction of a diversion facility to capture high flows and route them to the pipe.

4.3.3. Stop Degradation of Flow Regime

Stopping degradation of the flow regime, in this alternative, would involve getting some marginal improvement over the current trend of degrading stream health. This would not result in a stable stream system due to continued high erosion rates, and continued intervention would be required to stabilize banks and replace or enhance aquatic habitat.

One alternative for accomplishing this goal is to create the maximum amount of new stormwater detention within the watershed. Two new regional detention ponds would be constructed in the vicinity of the golf course, providing approximately 260 acre-feet of flood storage, and the outlet to Bow Lake would be modified to provide an additional 25 acre-feet of flood storage.

Habitat restoration work would be performed at a variety of locations below South 200th Street, and fish passage past the culvert at Marine View Drive would be provided. Planning-level cost estimates for the large detention ponds is $8 M ($4 M each). Planning-level cost estimate for the modification of Bow Lake is $80,000. A moderate level of habitat improvements to the area below South 200th Street would cost approximately $260,000. While current estimates for replacing the culvert at Marine View Drive culvert are available, the portion of the project cost attributed to fish passage has not been identified. Estimates for the cost of increased regulation are expected to be non-trivial.

A second alternative would involve the construction of a new high flow bypass pipe (on the order of 36 - 42 inches in diameter) along with an inlet facility and a diffuser-discharge facility in Puget Sound. This pipe would capture stream flows above a specified volume and route them safely through a pipe to Puget Sound. The new bypass pipe is assumed to follow the existing stream course and/or the sewer right-of-way. Habitat restoration work would be performed on the reach below the sewer plant, and fish passage past the culvert at Marine View Drive would be provided. Planning level cost estimate for a new bypass pipe is approximately $2.5 - 3.5 M. A moderate level of habitat improvements to the area below the sewer plant would cost approximately $260,000. While current estimates for replacing the culvert at Marine View Drive culvert are available, the portion of the project cost attributed to fish passage has not been identified.

4.3.4. Achieve Stable Flow Regime and Reduce Erosion Rates

Attaining a stable stream system would involve reducing stormwater flows to a level at which natural processes (such as bank erosion and bedload transport) would occur at rates which the stream channel could tolerate. Urbanization typically accelerates the rate of many natural processes. The goal of a stable stream system would be for these processes to occur at a slow enough rate that the rest of the stream system could accommodate the change. In this scenario the occurrence of failures, such as bank failures which destroy riparian habitat and threaten the pipelines, would be substantially reduced but would not be eliminated. Indeed, a completely stable stream system would be undesirable since northwest streams are adapted to periodic flooding, migration of stream channels within the floodplain, and regular movement of bed materials.

One alternative for attaining a stable stream system would be to construct a new high flow bypass pipe on the order of 48 - 60 inches in diameter, along with an inlet facility and a diffuser/discharge facility in Puget Sound. This pipe would capture stream flows above a specified discharge and route them to Puget Sound. The new bypass pipe is assumed to follow the existing stream course and/or the sewer right-of-way. Habitat restoration work would be performed on the reach below the sewer plant and in the ravine above the sewer plant, and fish passage past the culvert at Marine View Drive would be improved. Planning-level cost estimates for a new bypass pipe is approximately $8.5 - 9.9 M. A moderate level of channel and habitat improvements to the areas below South 200th Street would cost approximately $260,000. Total project cost would be approximately $8.7 - 10.1 M plus the fish passage enhancement portion of the Marine View Drive culvert replacement.

A second alternative for attaining a stable stream system would involve creating the maximum possible amount of detention capacity within the watershed. Two major regional detention facilities would be created in the vicinity of the golf course, the outlet to Bow Lake would be modified to provide additional detention, and regulations covering on-site detention requirements for new construction would be made much more stringent. The detention facilities would provide approximately 260 acre-feet of storage, Bow Lake would provide another 25 acre-feet, and regulatory changes would provide an additional 110 acre-feet for a total of 395 acre-feet. Planning-level cost estimates for this alternative would be approximately $8M, plus the fish passage enhancement portion of the Marine View Drive culvert replacement.

A third alternative for attaining a stable stream system would involve the creation of a combined regional detention facility and a minor flow bypass. This would involve the creation of a single regional detention facility in the vicinity of the golf course, the conversion of the about-to-be-abandoned Midway Sewer District pipeline to a flow bypass pipe, and the construction of a second small bypass pipe as part of Phase III. The combination of the detention facility and flow bypass is extremely effective at reducing stormwater impacts to the stream system. Planning-level cost estimates for this alternative are approximately $6M.

4.4. Selection of Preliminary Solution

Due to budget limitations it was not possible to fully analyze the cost and effectiveness of all of the potential solutions at each of the different levels of general stream health. Table 4.1 outlines the project costs and effectiveness. Planning-level cost estimates indicated that there was not a substantial difference in cost between maintaining the current flow regime and improving the stream to reach a stable flow regime. Very low cost solutions (No Action, Small By-Pass) were also extremely ineffective at providing any semblance of long-term protection to the stream.

Discussion at the Project Management Team level indicated that there was consensus among the jurisdictions that the level of general stream health desired was a stable stream system. Accordingly, only those alternatives meeting this performance standard were analyzed in more detail (see Section 5).

Table 4.1 Preliminary Alternatives

Policy Alternatives	Project Alternatives	Project Cost	Effectiveness	Other Considerations
No Action: Ongoing Degradation	Do Nothing	$0	Accelerating stream degradation.	Substantial hidden costs.
Slow Rate of Degradation	2 detention ponds	$8 M ($4M each)	Stream continues to degrade, but rate remains about the same.	Large cost for little improvement.
	1 detention pond and increased regulations	$3 M + regulatory costs	Stream continues to degrade, but rate remains about the same.	Little improvement in stream conditions, regulatory changes problematic.
	1 small detention pond and small bypass pipe	$4 M	Stream continues to degrade, but rate remains about the same.	Very similar to recommended project except for effectiveness.
	Small bypass pipe and increased regulations	$700,000 + regulatory costs	Stream continues to degrade, but rate remains about the same.	Little improvement in stream conditions.
Stop Degradation of Flow Regime	Maximize Detention (2 large ponds, Bow Lake)	$8 M ($4M each)	Stream degradation slows or stops.	Difficult siting issues and regulatory challenges.
	Mid- size bypass pipe	$2.5 M- $3.5 M	Stream degradation slows or stops.	Moderately effective, but siting bypass pipe difficult.
Stable Flow Regime and Reduced Erosion Rates	Large bypass pipe	$8.7 M - $10.1 M	Stream degradation stops, lasting habitat improvements possible.	Very effective, but siting large bypass pipe very challenging. Siting issues could affect costs.
	Maximize Detention and increased regulation	$8 M + regulatory costs	Stream degradation stops, habitat improvements possible.	Difficult siting issues and regulatory increases problematic.
	1 large detention pond and small bypass pipe	$5 M	Stream degradation stops, habitat improvements possible.	***Recommended alternative***. Can be phased. Almost as effective as large bypass, with better water quality improvements.

5. IMPLEMENTATION ALTERNATIVES FOR IMPROVED/STABLE FLOW REGIME

This chapter describes only those alternatives that would come close to producing a stable stream system if they were implemented (see Section 4 for a discussion of this policy choice). As discussed in the previous chapter, there are numerous project alternatives and potential tools which could be applied to the surface water challenges facing the Des Moines Creek basin. To help narrow the choices and the need for subsequent analysis, the Project Management Team first addressed the question of the desired outcome for the stream system.

Preliminary analysis showed that inexpensive projects would not produce anything resembling a healthy stream system. The preliminary analysis also showed that there was not a great cost difference between alternatives which produced a stable stream system and those which allowed continuing degradation of the stream. Given this, the Project Management Team directed staff to focus the remaining analytic effort on developing alternatives which produced a stable stream system.

5.1. Alternative: Maximum Detention & Increased Regulation

One alternative for achieving a stable flow regime capable of supporting constructed habitat improvements and a more robust fish population is to construct the maximum feasible amount of detention in the upper basin, above South 200th Street. An analysis of the maximum feasible detention storage in this upper basin was conducted to determine the magnitude of peak flow and durational improvements that could result from detention alone. As part of this analysis, sites that had previously been identified as potential locations for detention were examined for effectiveness at meeting detention goals (see Section 4.2.3 for a summary of other sites). The result of this analysis was selection of the Tyee Golf Course/Northwest Ponds site as the most logical place for major regional storage. The golf course/Northwest Ponds site is uniquely situated in the basin at the confluence of the two major branches of Des Moines Creek, yet it is upstream of the higher quality habitat reaches most in need of protection from high flows. Because of its unique location and the compatible land use, storage at the golf course/Northwest Ponds can be an effective tool in providing a more stable flow regime to the Des Moines Creek ravine.

By coupling maximum storage at this site with more strict regulatory standards for new developments and minor storage enhancements at Bow Lake, this "maximum feasible R/D" alternative yields approximately 395 acre-feet of new flood storage within the watershed.

The individual components of this proposal are described below:

1) Two major regional retention/detention ponds at the golf course site:
    a. The first of the regional ponds would be located at the site of the existing Northwest Ponds wetland. This facility would consist of an impoundment created by a twelve-foot berm constructed on the West Fork near the alignment of the current maintenance access road, approximately 1,000 linear feet downstream of the

Northwest Ponds outlet. This berm, coupled with extensive excavation in Phase II, would enhance the natural storage functioning of this wetland system by creating a pond with approximately 240 acre-feet of active flood storage. (By contrast, existing flood storage in the Northwest ponds wetland is approximately 90 acre-feet.) The structure would be designed to store water for both the Northwest ponds and Tyee Pond branches of Des Moines Creek, by constructing a pipe from the Tyee Pond outlet to the new regional pond. The outlet could be designed to incorporate aeration to raise dissolved oxygen levels.

b. The other regional detention pond would be located just above South 200th Street, where an excavated pond with approximately 110 acre-feet of live storage would be created. Des Moines Creek would be a direct inflow to this pond, so that it too would be able to manage flows from the entire upper portion of the Des Moines Creek basin.

2) Modifications to the outlet control structure at Bow Lake to reduce the lake level by about 2 feet, resulting in an additional 25 acre-feet of flood storage.

3) Stricter surface water detention standards would be placed on new development in the basin. These standards, similar to those proposed for Level 2 Flow Control in the draft King County Surface Water Design Manual, would require all new developments to control not only peak flows, but flow durations as well. Application of this standard throughout the Des Moines Creek basin would be expected to provide about 110 acre-feet more than that required by the current peak rate flow control standards.

Even with all of this additional storage in the basin, the ability to recapture a stable flow regime is uncertain. The nearly 400 acre-feet of new flood storage provided by this alternative would still be less than the overall quantity of soil column storage lost to historic development, most of which occurred with no mitigating flow detention whatsoever. Hydrologic analysis indicates that implementation of this alternative would result in a small reduction in 2-year to 10-year peaks and a 60 percent drop in the amount of stream erosion (also known as erosivity) anticipated, compared to current conditions (this assumes full build out to current zoning).

The total cost of the measures described under this alternative would be approximately $7.6 million in construction of the new ponds, and retrofitting the outlet of Bow Lake. Additional costs would be borne by the development community through the adoption of stricter standards. The capital costs for the project are summarized in Table 5.1. Most of this cost would be associated with the excavation and disposal of materials. If the material was found to be suitable for one or more of the major construction projects which may take place in the near vicinity (e.g., the 3rd runway, SASA, or Highway 509), then substantial cost savings might be possible.

Table 5.1 Capital Costs Associated With Maximum Feasible R/D Alternative

Facility	Location*	Storage Vol.	Est. Cost
Bow Lake Outlet	Bow Lake (Tributary #0377, RM 3.5)	25 acre-feet	$ 80,000
Regional Pond #1	NW Ponds (Tributary #0379, RM 0.1)	240 acre-feet (150 new)	3,600,000
Regional Pond #2	above S. 200th St. (Tributary #0377, RM 2.1)	110 acre-feet	3,900,000
Adoption of More Strict R/D Standard	Basin-wide	110 acre-feet	not estimated
TOTAL		**395 acre-feet (additional)**	**$7,600,000 + add'l development costs**

* See Figure 1.2 for river mile locations.

5.2. Alternative: Major Constructed Flow Bypass

Alternative 2 would provide for a stable stream through construction of a large bypass pipeline conveying flows from the Tyee Golf Course area to the mouth of Des Moines Creek. In order to substantially improve the flow regime, a design discharge of 170 cfs was chosen. This high-capacity bypass would reduce current peak annual flows in the mainstem below South 200th Street by over 50 percent even at full buildout conditions. Flow erosivity in the mainstem would be reduced to approximately the pre-developed, forested level.

In order to achieve this diversion of 170 cfs, a 54" concrete pipe would be required. Alternatively, a fused polyethylene pipe could be used, which would allow for a slightly smaller pipe size due to the reduced friction losses of the material and the ability of the fused pipe to carry flows under pressure through some of the lower gradient sections. In spite of these benefits, it is likely that a 42" to 48" high density polyethylene (HDPE) pipe would be required. As HDPE is a substantially more expensive pipe material than concrete, the use of a smaller diameter HDFE pipe would be unlikely to result in cost savings. Either way, flow would be diverted using a concrete weir installed on the golf course in the stream reach immediately above South 200th Street, and the new diversion pipe would be placed adjacent to the alignment of the existing sewer lines, along Des Moines Creek.

The proximity of this diversion to the existing lines raises some feasibility issues. The new pipe would be laterally constrained by Des Moines Creek to the east and the ravine wall to the west, and vertically constrained by the three existing pipes (the IWS, the new Midway line, and the abandoned Midway line). Construction might necessitate widening the access road and purchase of some additional right of way.

The cost of this alternative is estimated at $6.7 million, assuming the concrete pipe option is used. This estimate does not include any additional ROW costs or any costs associated with relocation of existing infrastructure.

5.3. Alternative: Combined Regional R/D with Flow Bypass

The third alternative for provision of a stable flow regime for Des Moines Creek would be combining a lesser level of regional R/D with a minor bypass of flood flows utilizing existing soon-to-be abandoned pipes.

A combined project would be particularly effective at moderating storm flows. One of the biggest challenges to operating an effective detention pond is preparing it to deal with several storms in a short period of time. Because the purpose of a detention pond is to store water and reduce peak flows, detention ponds typically store water for a number of days after a storm event. Detention ponds are limited in how fast they can discharge stored water by the capacity of the downstream channel. During flood season, several storms will often arrive within a day or two of each other and detention ponds will not have had a chance to finish draining from the first storm when the second storm hits. Since the pond is already partially full when the second storm hits, the pond is not capable of storing as much water and it does not moderate peak flows as effectively as if it had been empty when the storm arrived.

A combined project uses the best features of both a detention pond and bypass pipe. The pond still stores water during a storm event and discharges to the stream at a flow level that does not damage the channel. The bypass pipe drains water directly from the pond and discharges it to Puget Sound, greatly reducing the time needed for the pond to be emptied and ready for the next storm.

By using both a pond and a bypass pipe together, substantial improvements to effectiveness of stream protection can be obtained at a smaller overall cost. The combined project allows both the pond and the bypass pipe to be smaller and takes advantage of the possible capital savings available through use of the sewer line. This results in both land and construction costs being smaller than either the pond or the bypass pipe would be on its own.

One of the secondary benefits of this alternative is that it could reduce both the frequency and duration of flooding on Tyee Golf Course, at the south end of the Airport. Flooding and standing water in the vicinity of active flight areas are major safety concerns with the Port and the Federal Aviation Administration and are actively discouraged. While this alternative would involve construction of a stormwater storage facility at the south end of the airport, operation of the facility could actually reduce the danger of bird strikes by reducing the frequency of flooding, the amount of surface area flooded during most storms, and the duration of standing water on the golf course. The bypass pipe would have sufficient capacity to convey flows up to one-half of the 2-year event away from the site; thus reducing the flooding associated with high frequency events. In addition, creation of more substantial buffers along the stream could further reduce the attraction this area would present to passing birds while improving water quality and trout habitat.

The specific components of this alternative would be as follows:

1) A single detention pond on the golf course. This would be the same regional pond at the Northwest ponds site described in the maximum detention alternative. This would provide 240 acre-feet of flood storage.

2) The same Bow Lake outlet modifications as described in the maximum detention alternative, resulting in 25 acre-feet of additional flood storage.

3) Use of the soon-to-be-abandoned sewer line for diversion of flood flows. The 24" Midway sewer line will be available in the near future, as the Midway Sewer District is constructing a larger pipe system during the summers of 1996 and 1997, and will abandon the existing line in place. In a later phase of the project, the existing 18" IWS line could be used for an additional division if it is also abandoned (a decision on abandoning the IWS line has not yet been made).

4) This alternative could include a number of conveyance and in-stream habitat improvements along the golf course reach of Des Moines Creek, both above and below the proposed detention pond outlet. Tyee Golf Course currently experiences flooding problems related to inadequate stream gradient in the reach between the Northwest Ponds outlet (RM 0.20) and the confluence of the West Fork and Des Moines Creek. This 1,100 foot stream reach overflows several times per year. Construction of the large detention pond would provide an opportunity to improve the gradient, relieving the flood problem except during major events requiring pond storage. For smaller events, the diversion pipe would convey floodwaters away from the area. Such reconstruction of the stream would require further work below the detention pond, to reduce the stream gradient in the reach between the pond and South 200th St. In-stream habitat structures could be incorporated into this lower reach to improve fish production.

The total cost of this combined detention and bypass alternative would be approximately $5.2 million, with the conveyance and habitat improvements. An advantage of this flow reduction alternative is that it could easily be constructed in several phases, allowing both costs and construction impacts to be spread over a number of years if desired. The costs of each of the components of the alternative are summarized in Table 5.2.

Table 5.2 Capital Costs Associated with Combined R/D and Bypass Alternative

Facility	Location	Specifications	Est. Cost
Bow Lake Outlet	Bow Lake (Trib 0377, RM 3.5)	25 acre-feet	$ 80,000
Regional Pond #1	NW Ponds (Trib 0379, RM 0.1)	240 acre-feet (150 new)	3,600,000
Golf Course Conveyance & Habitat Improvements	Des Moines Creek, RM 2.1 to 2.35, & Trib 0379, RM 0.0 to 0.2		160,000
24" High Flow Bypass Diversion Pipe	NW Ponds to Des Moines Creek Mouth	24" RCP	670,000
18" High Flow Bypass Diversion Pipe	NW Ponds to Des Moines Creek Mouth	18" RCP	630,000*
Total			**$5,200,000**

*Cost would be substantially more (approximately $2 million) if IWS line is not available.

Even with all expected future development in place, this alternative would reduce peak annual flows by approximately 50 percent and stream erosivity by 75 percent compared to current conditions. Although it does not fully restore pre-developed, forested flow conditions, it is significantly more effective and less costly than the maximum detention alternative and nearly as effective as the major bypass alternative at somewhat less cost.

5.4. Flight Safety Concerns

One issue of concern common to all of the alternatives examined in detail is the close proximity of diversion and detention structures to the active runways at Sea-Tac Airport. Federal Aviation Administration (FAA) regulations discourage creation of open water within 10,000 feet of an active runway due to potential collisions between birds and airplanes. The premise for this regulation is that standing open water attracts waterfowl and other birds to the vicinity of aircraft operation, and that ingestion of waterfowl by operating jet engines can lead to engine failure and a possible airplane crash. Safe flight operations is a very high priority for the Basin Committee and the proposed alternative projects have all been designed to reduce, rather than increase, the duration and frequency of surface water ponding over existing conditions

Based on recent experience, flooding of Northwest Ponds and the Golf Course area along the West Tributary between the ponds and the road currently occurs on average several times per year and lasts an average of 2 to 3 days. This flooding both expands the surface area around the ponds, and causes overbank flow and standing water in the floodplain of the West Tributary of the creek between the ponds and the approach light road. The pooling of water and especially shallow water represents a significant concern for the airport's wildlife management program because shallow open water tends to attract water fowl; and the presence of water fowl near runway approaches represents a safety hazard that must be minimized. Consequently, it was necessary to analyze the impact of implementation of the preferred solution (bypass plus storage) on the frequency and duration of pooled water in the area.

Table 5.3 summarizes the results of this analysis. The table describes two levels of increased standing surface water which would result from storm events, events that create an additional 3 acres (approximately) of standing water and events that create an additional 6 acres (approximately) of standing water. Note that the base or 'dead storage' surface area of Northwest Ponds is currently approximately 12 acres. Therefore, the 3 acre column in the table represents flood conditions under which total surface area has increased by approximately 25 percent, and the 6 acre column represents a 50 percent increase of total pool surface area. As shown in the table, under current conditions the total ponded surface increases from 12 acres to more than 15 acres approximately two to three times per year for an average duration of two to three days per event. Similarly, the table shows that 6 additional acres around and downstream of the ponds are covered with standing water one to two times per year for one to two days on average. Currently during winter floods, water overflows the banks of the backwatered outlet channel and pools on the golf course. The area of this overbank flooding represents approximately 40 to 50 percent of the total increase in pool surface area with the remaining portion occurring around the perimeter of the ponds.

Analysis of the alternatives for creating detention in the vicinity of the Northwest Ponds involved hydrologic modeling runs based on current land use conditions in order to make a consistent comparison with the observed current ponding condition. Future land use changes can be expected to exacerbate flooding in the vicinity of the golf course. Due to limited survey information, the estimated inundation areas must be considered approximate.

One component to improving the high frequency flooding conditions on the golf course will be to regrade the stream channel below Northwest Ponds to improve velocities through that reach. This component, combined with careful grading of the entire project site, will ensure that drainage conditions are improved during high frequency storm events and that stormwater is efficiently diverted into the abandoned 24-inch line. The increased stream gradient below Northwest Ponds will then necessitate gradient reduction farther downstream in the reach between the confluence with the Tyee Ponds branch and South 200th Street. Habitat and water quality amenities can be built into the regraded stream segments, as described elsewhere in this report. Retention of the existing weirs below the confluence, or provision of structures with similar functions such as boulders or logs, would be needed in order to continue improving dissolved oxygen concentrations in this reach. If these structures were removed without their function being replaced, water quality problems in downstream reaches would likely increase.

Several options for detention in the vicinity of the approach light road and Northwest Ponds were examined during the analysis of the combined detention/bypass alternative to determine what general level of effectiveness could be anticipated if this alternative were pursued. As shown in table 5.3, each of the various options for this alternative are successful in reducing all aspects of flooding under the flight path from the airport. Flooding frequency, flooding duration, and aerial extent of flooding is reduced over existing conditions in each of the potential locations for the detention pond berm.

This analysis makes it clear that even the simplest detention pond in this location would dramatically reduce the duration of flooding in the vicinity of the flight path and presumably reduce bird strike issues related to the extent of open water) while protecting the downstream reaches of Des Moines Creek. Due to the limited extent of information available at this preliminary stage, it is not possible to provide a recommendation regarding the specific location for the detention pond berm.

Specific location of the detention pond berm and outstructure, and other construction details will be determined during the preliminary design phase of this project. During the preliminary design phase a number of criteria will be analyzed to determine their effect on overall design of the detention pond. The Project Management Team, in consultation with their jurisdictions, will seek to develop an optimum balance of these competing needs in preparing their recommendation.

Criteria considered in developing a final recommendation for the detention pond configuration will include overall cost including land costs and operation and maintenance costs, ease of construction, ease of permitting, effect on potential bird strikes and mitigation for wildlife attraction, effect on flooding in the vicinity of the golf course, effectiveness of protecting downstream reaches of Des Moines Creek, affect on wetlands, effect on water quality, additional maintenance required by airport operations or FAA regulations, other safety concerns, interactions with other large projects currently being considered for the area, ability of the recommendation to accommodate additional stormwater storage needs for projects on Port of Seattle properties, anticipated mitigation requirements, and affect on future land use of the site. Other criteria may be developed by the PMT during the course of the preliminary design phase.

Table 5.3 Estimated Reductions in Flooding for Tyee Golf Course/Northwest Ponds

	~3 acres additional surface pooling		~6 acres additional surface pooling		GOLF COURSE FLOODING (Between NW Ponds and Approach Light Road)
SCENARIO	**AVG # EVENTS/YR**	**AVG DAYS/EVENT**	**AVG # EVENTS/YR**	**AVG DAYS/EVENT**	
Current Conditions	2 - 3	2 - 3	1 - 2	1-2	Very Frequent (2-3 times/yr for 2 days)
Detention Berm at Approach Light	2 - 3	~1.0	~.9	~1.1	Frequent (1-2 times/yr, for 1 day)
Detention Berm on Golf Course	2 - 3	~1.0	~.9	~1.1	Very Infrequent (Less than once in 50 years, for less than 1 day)
Detention Berm around NW Ponds	<1 in 50	<<1	<1 in 50	<<1	Very Infrequent (Less than once in 50 years, for less than 1 day)

NOTE: Due to limited topographical information, these are planning level estimates only

5.5. Special Cases:

5.5.1. Buildings in Beach Park

The several buildings comprising the senior center in Des Moines Creek Beach Park are located directly within the Des Moines Creek floodplain, and begin to flood at a discharge of approximately 175 cfs, based on a recent study conducted by a Seattle University project team. This is approximately a 2-year flow under current land use conditions.

Various proposals for resolving this problem have been put forth in the past, including construction of substantial regional detention in the upper parts of the Des Moines Creek system in order to lessen the frequency and severity of flooding at the senior center. While this plan proposes detention as a useful approach to reducing high flows and habitat degradation in Des Moines Creek, such detention is not a cost-effective option for protecting the senior center.

Recently, the City of Des Moines has begun to consider resolving the senior center flooding problem through relocation of the buildings. Given the expectation that this solution will be carried out in the near term, city engineering staff and the Project Management Team representative requested that the senior center's flooding not be considered for solution under this basin plan. Relocation of the center does appear to be the most cost-effective alternative for reducing the flood hazard associated with the buildings and may provide an opportunity for future stream and delta restoration within the park as well.

5.5.2. Culvert at Marine View Drive

As mentioned earlier in this report, the Marine View Drive culvert is scheduled to be replaced with a joint use short bridge that will convey flows while also providing pedestrian access to a proposed trail system that will extend both up- and downstream of the roadway fill.

The current culvert is a 225-foot long 4' x 6' concrete box culvert at a slope of 2.33 percent. This culvert is capable of conveying flows up to and including the 100-year event without overtopping of Marine View Drive, largely because of the height of the road embankment. Even so, hydraulic conditions are far from ideal. The inlet to the culvert becomes submerged at approximately 200 cfs, which is less than a 5-year discharge. At flows above this level, ponding occurs on the upstream end of the culvert, creating potential safety issues since the road fill was not designed to function as a dam. In addition, flow velocities through the culvert are greater than those recommended for upstream fish passage at all flow levels, effectively isolating habitat upstream of the culvert from any extensive use by salmon.

This plan does not fully consider options for replacing the culvert, but the analysis herein suggests that an improvement would be highly beneficial, especially with regard to fish passage. Upgrading the culvert will have a minor effect on downstream flows, as the area behind the embankment provides storage only at flows greater than a 2-year recurrence interval. The senior center and several road and pedestrian crossings in Des Moines Beach Park are the only structures located downstream of the culvert, and the senior center floods at 175 cfs, before the storage effect becomes important. Thus, the culvert effects the magnitude, but not the frequency, of senior center flood flows. If the culvert is upgraded without removing the senior center buildings, then larger flood flows (5-year frequency and above) would be greater at the site of the senior center than with the current culvert in place.

The cost of replacing the culvert with a joint-use short bridge as described above has been estimated at $4 million by Shannon & Wilson, the City of Des Moines' consultant.

5.5.3. Flow Augmentation

Des Moines Creek has several water quality problems which contribute to the overall stress facing the aquatic ecosystem. Temperature is a critical issue for salmonids, and during summer months the temperature of water in the Creek in the vicinity of the golf course is so warm that it is nearly fatal to salmonids. During summer months, dissolved oxygen levels in the Creek in the vicinity of the golf course are sufficiently low that they also produce substantial stress to salmonids. Dissolved oxygen reductions are due in part to elevated water temperatures and in part to organic material in the water column which produces a higher Biological Oxygen Demand (BOD). Organic material comes from algae blooms in Bow Lake and Northwest Ponds, and from animal waste originating around Bow Lake and Northwest Ponds.

In addition to water quality problems, the Creek faces an increasingly difficult challenge as summer flow levels get smaller and smaller due to changes in land use. The same conversion of forest to impervious area which makes storm peaks larger during the winter also makes summer flows smaller. This is because the primary source of water for summer low flows is groundwater, and groundwater recharge is being reduced as forest is converted to impervious area. Low flow stream levels are particularly important to fish populations in small systems such as Des Moines, and often serve as one of the principal limiting factors to overall fish production.

All three of these stream problems (elevated temperatures, lowered dissolved oxygen levels, and reduced stream flow) occur during the summer months when stream flows are at their smallest. All three of these problems can be expected to get worse in the future if no action is taken. To address these issues, this basin plan proposes the creation of a flow augmentation facility in the vicinity of the Tyee Golf Course.

The proposed flow augmentation facility would involve pumping groundwater to the stream during critical flow periods in the summer. Cool, high quality ground water would be drawn from an existing well and aerated by discharging it on to a rock pile before entering the stream. This additional flow could be used to address low flow conditions, elevated temperature conditions or depressed levels of dissolved oxygen.

The existing well extends to a depth of 600 feet below the surface and is cased to over 200 feet, so water drawn from the well almost certainly has no effect on flow levels in the Creek. Ground water sources which the well draws upon are below sea level and are on their way to discharge directly to Puget Sound or potentially other deep water supply wells in the general vicinity. Water quality samples taken from the existing well show that the well water is suitable for use in augmenting flow in the Creek during summer months. The existing well also has substantially more physical capacity for producing water than is presently being utilized. The Port of Seattle currently has a water right for 300 gpm for use in golf course irrigation, and the well is capable of producing 1200 gpm. The proposed flow augmentation facility would utilize approximately

400 gpm when it is operating. Current estimates suggest the facility would operate for several weeks during a normal summer low-flow period.

Costs for this facility would involve changes to existing well plumbing and pumps, and a small amount of pipe to convey the water from the well to the stream. The discharge location could be sited in the vicinity of the existing pump, adjacent to South 200th Street, or the discharge could be integrated into the berm and outlet facility proposed for the detention pond on Tyee Golf Course. Integration with the proposed berm and outlet facility would improve poor water quality conditions in a larger stretch of stream.

The facility could be operated manually or it could be automated. If operated manually, regular stream monitoring during summer months would be required to alert the operating crew to conditions warranting flow augmentation. Operation of the facility could be automated by establishing an automated water quality monitoring station and hooking the pump up to run whenever conditions triggered an alarm.

Estimated costs for the flow augmentation facility, assuming manual operation and discharge to the stream at South 200th Street, would be approximately $65,000. This improvement would require an additional water right from the WSDOE. Preliminary discussions indicate WSDOE would be likely to look favorable on such a request.

5.6 Summary of Implementation Alternatives

There were three different alternatives identified which could be effective in significantly improving, or potentially stabilizing, the stream flows in Des Moines Creek. These alternatives included maximizing detention capacity throughout the basin, constructing a major flow bypass, and constructing a combined detention/bypass facility. The combined detention/bypass alternative was further analyzed and three different options for location of the new facility were identified and investigated. Table 5.5 summarizes the estimated costs, the effectiveness in reducing erosion rates, and special considerations for each of these three alternatives for the combined facility.

Table 5.5 Summary of Implementation Alternatives for Improved/Stable Stream Flow

Alternative	Estimated Cost	Effectiveness	Considerations
Maximum Detention	$7,600,000	60% reduction in erosion	Safety concerns due to large open water area.
Major Bypass	$8,700,000 - $10,100,000	90%+ reduction in erosion	Extremely difficult to site large bypass pipe.
Combined Detention and Bypass	$5,200,000 - $7,200,000	75% reduction in erosion	Reduction in flooding on golf course. Possible permitting and engineering issues.

To assist in reaching a conclusion regarding which alternative to recommend figures 5.2 and 5.3 were prepared. Figure 5.2 shows both the relative effective flow energy and the cost for each of the main alternatives as well as pre-development conditions and current conditions. The relative effective flow energy compares the projected flow energy to the flow energy that occurred before logging and development of the basin. Flow energy is a summary of the amount of work that the stream does over a given period (usually a water year). In this figure, a low effective energy is desired as this indicates a lessening in overall energy which would also result in a lessening of erosion rates. The relative flow energy in the current condition is about 11 times as large as under the forested condition. It is notable that both the combined facility and the large bypass alternatives produce effective flow energy to nearly the forested flow energy levels, which is less than 20% of the current level of effective energy in the stream system. The combined facility alternative achieves these results at a lesser cost than the large bypass alternative.

Figure 5.3 shows the relative effectiveness of the various alternatives in reducing the size of peak stream flows, and also compares their overall costs. This figure shows the change in peak flow volumes, the largest flow level during storm events, and is an indicator of the extent of flooding that would occur under the different alternatives. While current conditions result in peak flows that are four times as large as predevelopment conditions, both the combined facility and the large bypass can effectively reduce peak flow volumes. The combined facility is almost 50% more effective at reducing peak flows than the large bypass facility, and is also less costly.

Figure 5.4 shows the predicted flood frequency curves for Des Moines Creek under current conditions and with each of the major alternatives. It is again notable that the combined facility does the most effective job at reducing flood flows to levels nearing the forested condition. Other alternatives are nearly as effective, particularly during the larger flood events when the most damage occurs.

Figure 5.2 Comparison of flow energy and cost of various alternatives.

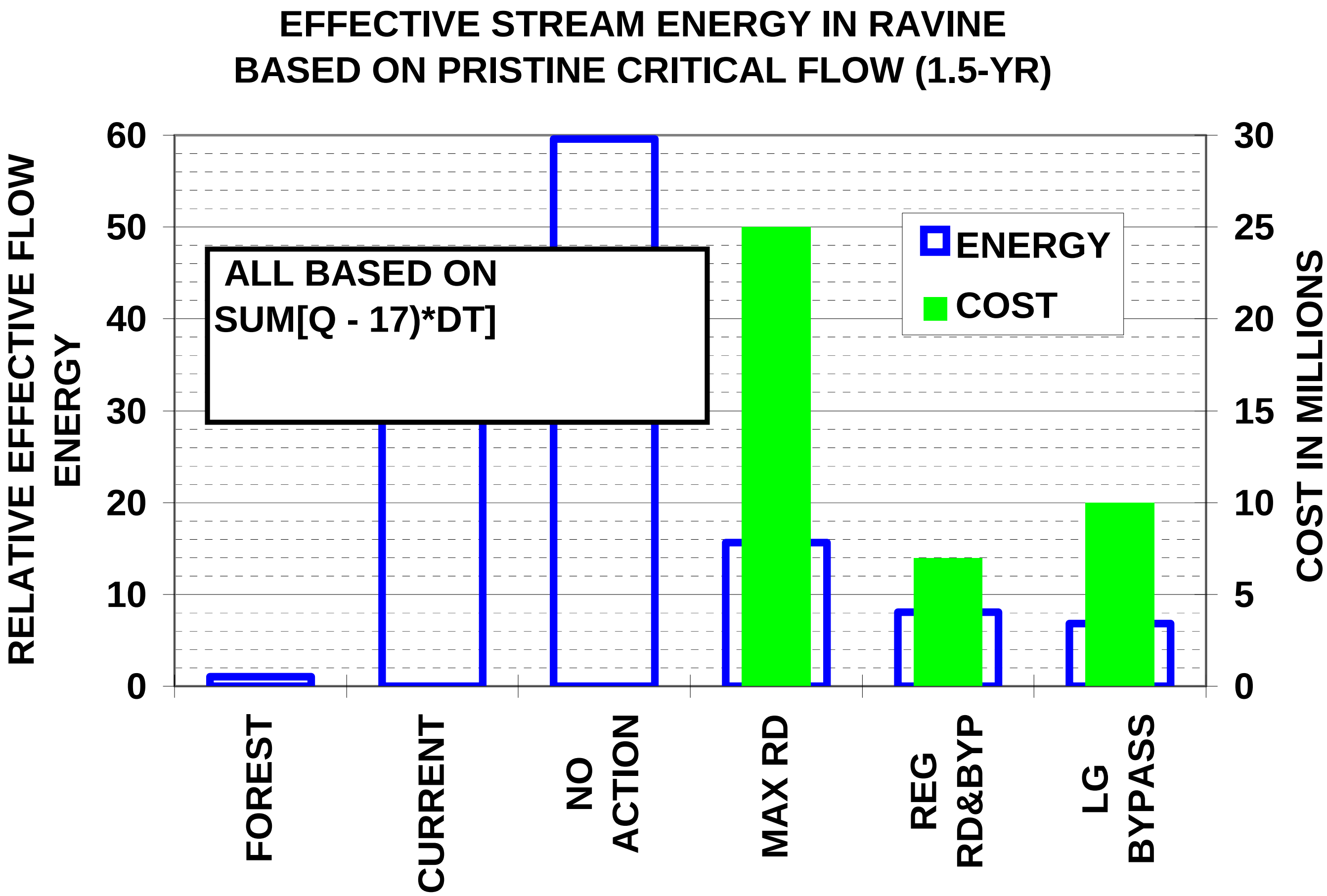


Figure 5.3 Comparison of various alternatives relative to stream flow and cost.

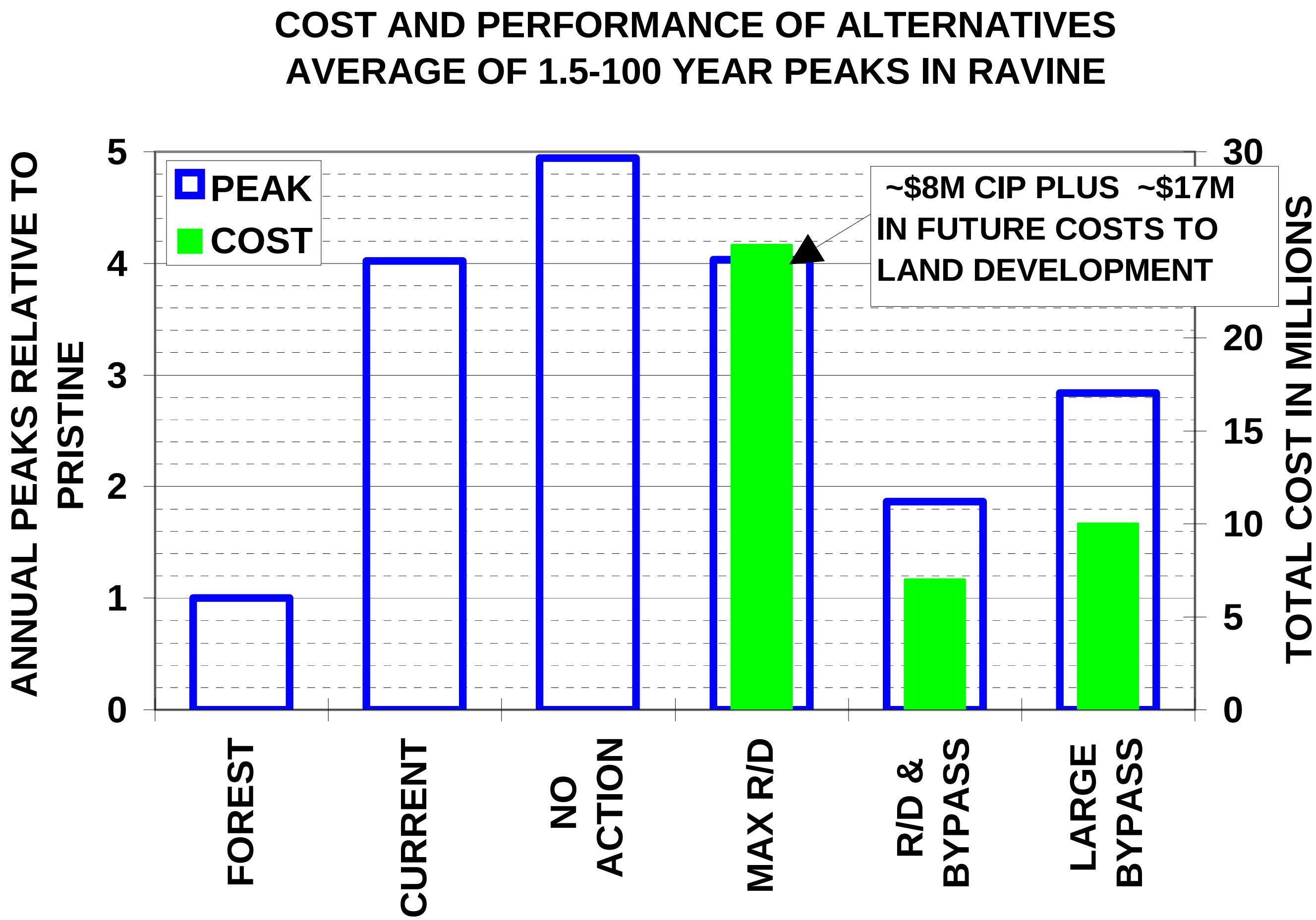
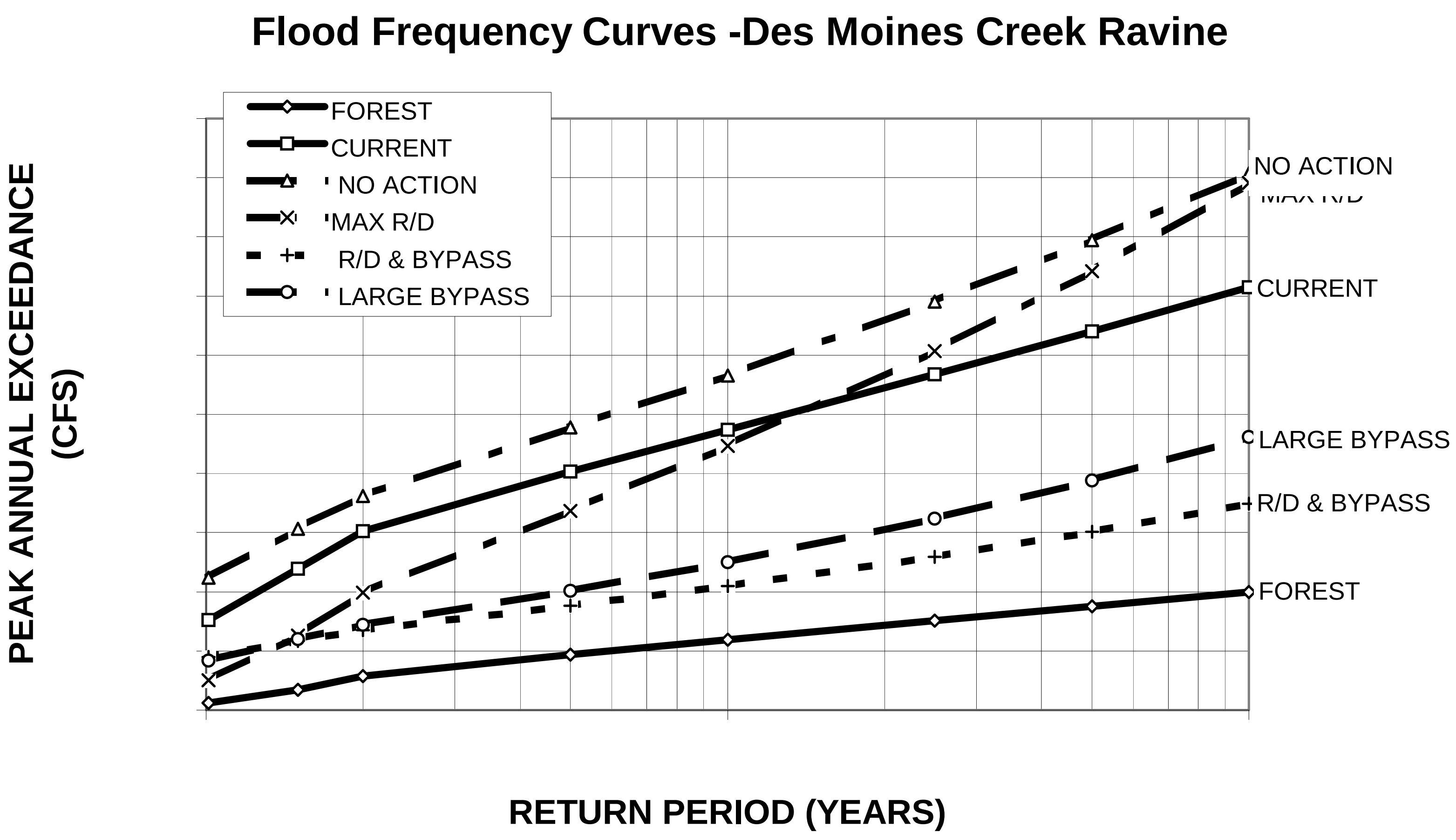
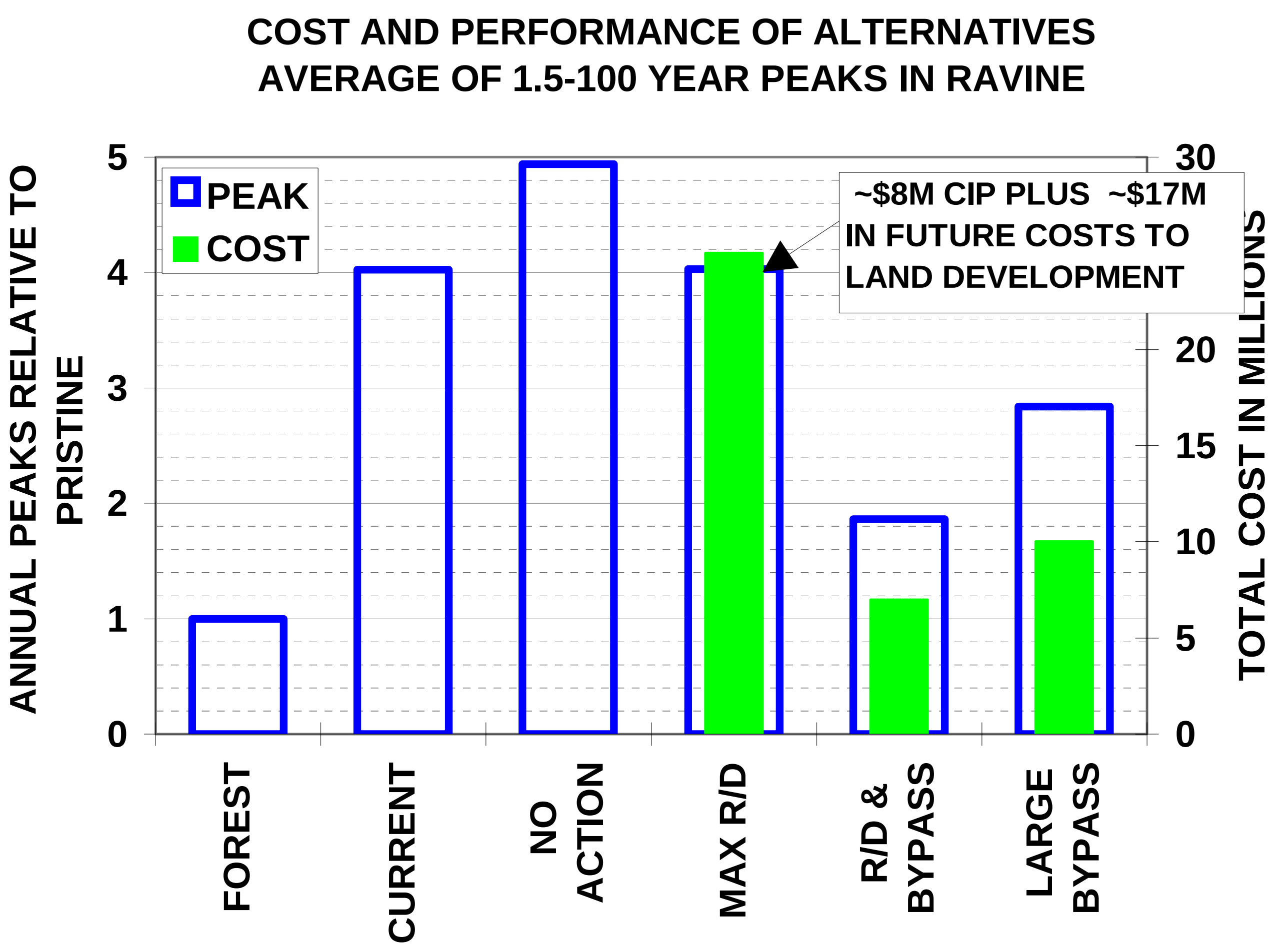


Figure 5.4 Comparison of predicted flood frequency for various alternatives.




COST AND PERFORMANCE OF ALTERNATIVES
AVERAGE OF 1.5-100 YEAR PEAKS IN RAVINE
ANNUAL PEAKS RELATIVE TO PRISTINE
TOTAL COST IN MILLIONS
PEAK
COST
~$8M CIP PLUS ~$17M IN FUTURE COSTS TO LAND DEVELOPMENT
0
1
2
3
4
5
0
5
10
15
20
30
FOREST
CURRENT
NO ACTION
MAX R/D
R/D & BYPASS
LARGE BYPASS

6. RECOMMENDATIONS

6.1. CIP Recommendations

6.1.1. Detention/Bypass Pipes

The recommended alternative for reducing flows in the lower portions of Des Moines Creek is the combined detention/ bypass alternative described in Section 5 of this plan. This alternative is the most effective and least costly of the three major alternatives that were evaluated. The project can be implemented in three phases, resulting in an up-front cost savings and an opportunity to further evaluate stream conditions prior to constructing Phases II and III. An evaluation of the effectiveness of Phase I should be performed, and subsequent phases should only proceed after the benefits of Phase I have been demonstrated.

The three project phases would be: (1) to design and install a control structure at the Northwest Ponds to divert flows and to better utilize the existing pond storage, and to utilize the soon-to-be-abandoned 24-inch-diameter sewer line for high flow bypass; (2) to excavate a larger detention pond at Northwest Ponds; and (3) to divert more flow, by constructing an additional small bypass pipe along the sewer line right of way. These phases are described in more detail below and are shown on Figure 6.1.

Initial Phase

The recommended initial phase of the detention/ bypass project is to utilize the abandoned 24-inch-diameter sewer line for high flow bypass, and to make minor detention enhancements at the Northwest Ponds site. The following measures would be necessary:

a. Construct a berm and control structure across the West Fork (Stream 0379), below the outlet of Northwest Ponds. This structure could be located upstream of the existing golf course access road at approximately RM 0.2 (see Figure 1.2). The control structure would be intended to make better use of the current storage volume at the Northwest Ponds by limiting outflows to predetermined levels. In order to limit downstream erosion and to protect investments in bank stabilization and stream habitat structures, no more than 20 cfs should be allowed to pass through the outlet before diversion to the abandoned sewer pipe begins. The newly constructed diversion pipe should then capture approximately 10 to 15 cfs before significant use of the pond storage begins. While the existing storage volume of the Northwest Ponds area approaches 90 acre-feet during flood events, the addition of the berm and control structure would allow for approximately 160 acre-feet of storage at an elevation of 250 feet.

b. Construct an outflow pipe from Tyee Pond to the newly impounded area, so that all flows from the Tyee Pond branch are diverted or stored along with the Northwest Ponds flows.

c. Construct a diversion pipe from the Northwest Ponds outlet structure to the upstream end of the abandoned 24-inch-diameter sewer line, just above South 200th Street. Two additional pipe sections will need to be constructed: 1) a 500 linear foot segment below South 200th Street, in a reach where the sewer line is not being abandoned, and 2) a reroute around the Midway Sewer District treatment plant. The total length of new pipe required would be approximately 3,300 linear feet.

d. Stream conveyance and habitat improvements in the reaches just above and below the new pond outlet to improve water quality and resident fish habitat. The stream gradient in the reach from Northwest Ponds to the diversion structure would be increased in order to reduce the frequency of overbank flooding of the golf course. The gradient from the detention pond downstream to South 200th Street would be decreased to compensate for this. The concrete weirs in this reach would be replaced with another weir or with a more natural feature such as boulders or logs to preserve their aeration function, and the stream channel would be rebuilt to accomplish this grade change. This would offer an excellent opportunity to improve stream habitat by increasing the channel length and installing large woody debris and other habitat features.

The construction cost for this initial phase is estimated at $2.2 million, including design and permitting.

Second Phase

The second phase of the combined detention/bypass project would be to increase the storage volume at the regional detention pond by increasing the berm height slightly and excavating approximately 50 additional acre-feet of storage within the 34 acre right of way utilized in Phase I. Modification of the pond outlet structure would be necessary to re-optimize the rating curve.

The estimated cost of the second phase is $2.4 million; however, the quantity of excavation could be modified based on results of stream monitoring and/or redefinition of objectives after the construction of Phase I.

Prior to commitment of Phase II, the health of the stream will be reevaluated. The purpose of this reevaluation is to ascertain the benefits of Phase I. The studies to be conducted will include but will not necessarily be limited to the following:

- Biological assessment including surveys of the physical habitat, fish populations, and invertebrate populations, and an evaluation of the condition of the fish habitat structures;
- Resurvey of channel cross-sections for erosion since the installation of the regional detention facility;
- Effect of the facility on the reduction of stream flows;
- Study of water temperatures and dissolved oxygen in the upper reaches of the watershed;
- Assessment of bird use of facility and potential aviation safety issues related to changes in bird use from existing conditions.
- Recalibration of the hydrologic model with stream flow data collected after Phase I completion, and new estimates of the desired capacity increase of the regional facility in Phase II.

Third Phase

The final phase of the combined detention/bypass alternative is somewhat less defined at this time. The approach that currently appears most useful would be to construct an additional diversion to supplement the 24-inch RCP utilized in Phase I. Recent discussions with the Port of Seattle have indicated that their 18-inch IWS sewer line may be abandoned in the future as its capacity may be inadequate for flood flows. This line runs the length of lower Des Moines Creek adjacent to the 24-inch RCP and is routed through the Midway Sewer District treatment plant. Abandonment will only occur if the Port of Seattle can find a cost-effective alternative for treatment of their industrial waste that completely obviates the need for the line. If this occurs, the 18-inch line would become an ideal candidate for a second flow diversion in Des Moines Creek. Utilization of the 18-inch line would require construction of at least two new pipe segments: one from the outlet of the Phase I pond to the upstream end of the 18-inch line, and another to route flows around the treatment plant. The outlet structure itself would require modification to again re-optimize for a new rating curve. Construction of a third phase under this scenario would cost approximately $630,000.

If the 18-inch IWS does not become available for stormwater diversion, then it may still be worthwhile to construct a new pipe. This would raise costs considerably and raise several feasibility issues given the number of stormwater and sewer lines that would already be located along Des Moines Creek. One alternative would be to construct a new 18- or 24-inch pipeline which would likely cost in excess of $2 million; another possibility would be to replace the 24-inch line from Phase I with a larger pipe.

6.1.2. Bow Lake Outlet Improvements

Concurrent with the Phase I improvements described above, the project team recommends that the improvements to Bow Lake be constructed. These consist of modifications to the outlet structure to allow the lake level to be reduced by approximately two feet during storm seasons, thereby increasing the active flood storage available in the lake by 25 acre-feet.

6.1.3. Marine View Drive Culvert

The recommendation of the project team is to support local efforts to remove the existing road fill and replace the existing Marine View Drive culvert with a bridge. The culvert replacement will more than double the aquatic habitat available to migratory salmon. Basin Plan team members are actively involved in development of design criteria for issues

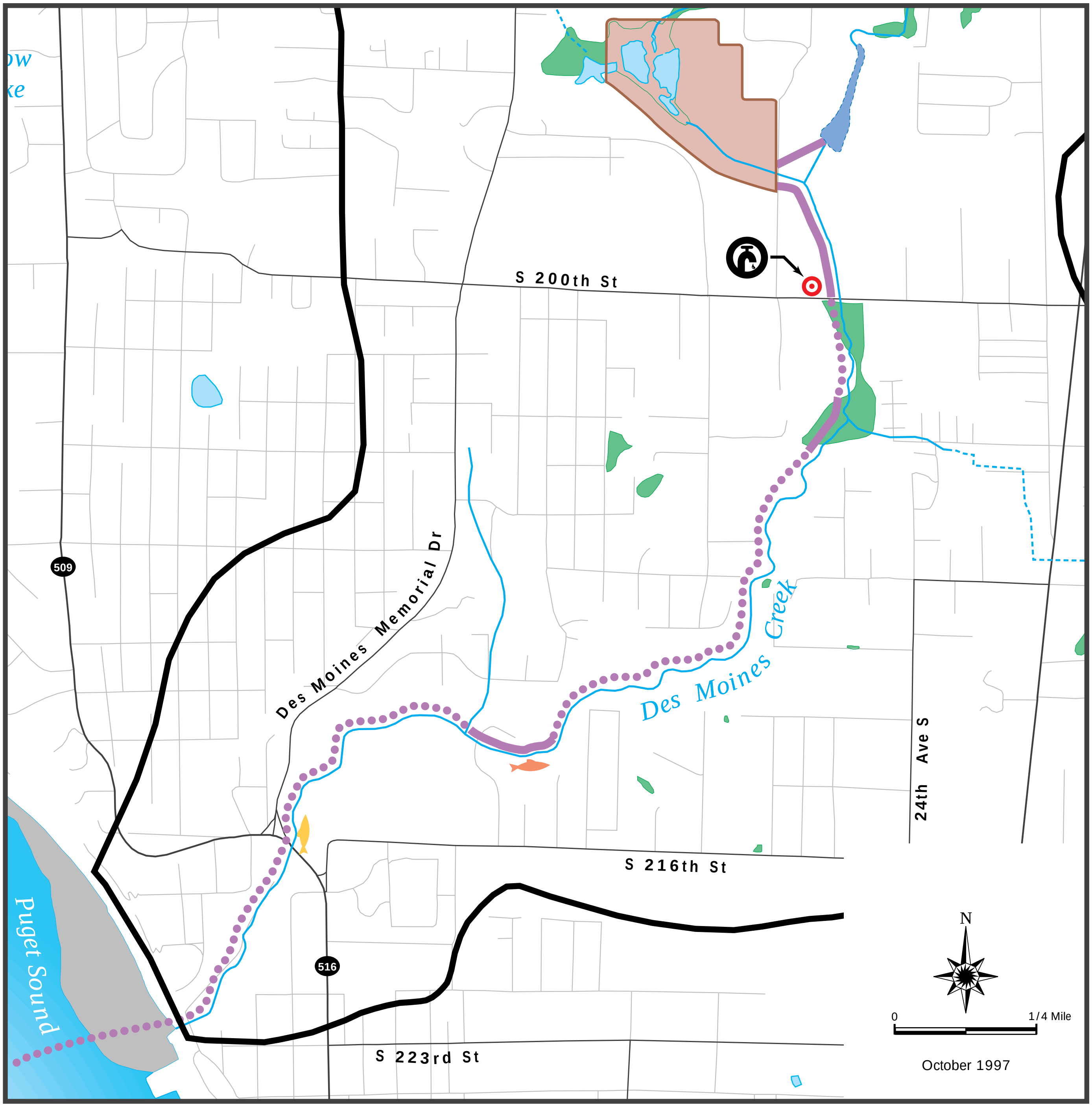


Figure 6-1

DES MOINES CREEK BASIN

Capital Improvement Projects

Phase 1

- Regional Detention Facility (Construct berm and outlet)
- Flow Bypass Pipe: New Pipe, Reused Pipe
- Fish Passage Improvement at Marine View Drive
- Flow Augmentation Facility

Phase 2-3

- Regional Detention Facility (Excavate, modify outlet)
- Fish Passage Improvement at Midway Treatment Plant

- Basin Boundary
- Stream
- Piped Stream
- Lake
- Wetland
- R/D Facility
- Shoreline

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regarding fish passage and stormwater flows. Fish passage is being designed to meet the conveyance and fish passage criteria in the Washington Administrative Code. Since the replacement is a multiple use project, and addresses recreational needs as well as stormwater and fisheries needs, funding is expected to come from multiple sources.

6.1.4. Low Flow Augmentation Facility

The project team recommends construction of the low flow augmentation facility in the vicinity of South 200th Street. This facility has a relatively minor cost (estimated at $65,000) and has the potential to provide significant benefits to the aquatic ecosystem during summer periods of stress caused by elevated temperature and low flow. Supplementing low stream flows with ground water could also be used to respond to low dissolved oxygen episodes.

The low-flow augmentation facility would also be useful in the event of a major chemical spill in the upper watershed by allowing the spill to be contained in the detention pond for clean-up while still providing a source of water to the stream channel. In the event that a chemical spill were to enter the lower system, the flow augmentation facility would be capable of providing a source of uncontaminated water for dilution of the spilled chemical(s).

Several issues associated with the low flow augmentation facility will need to be resolved during the design phase. A water right to utilize additional water from this well would need to be acquired from the WSDOE. Preliminary discussions indicate the WSDOE would likely to look favorably on such a request. An operational plan for the facility should be developed based on ongoing monitoring, and should identify conditions which warrant the facilities operation and the appropriate operation under each of those conditions. Likely critical factors triggering facility operation include elevated summer temperatures, low dissolved oxygen levels, inadvertent chemical spills upstream of the facility, and low summer flow levels.

The PHABSIM habitat model, previously used in this stream system, should be run again to identify potential habitat benefits which may possible through supplementing stream flows during summer months. This model is capable of examining the amount of habitat available at different flow levels. Since low flow levels and shallow stream depths are believed to be one of the limiting factors in Des Moines Creek, the PHABSIM model could identify whether any potentially substantial increase in fish productivity was possible due to operation of the flow augmentation facility during summer periods.

6.2. Aquatic Habitat Recommendations

6.2.1. Fish Management Goals

One of the goals of this watershed planning effort was to identify appropriate enhancement and restoration measures to improve fish habitat within the Des Moines Creek watershed. Fisheries field work, infrastructure investigations and water quality sampling were used to identify fish enhancement measures as part of this effort. The project team recommends that the watershed be considered as three separate zones for the purposes of fish management issues (see Figure 6.2).

Zone 1 would included the lower portions of the watershed (Beach Park Reach, Sewer Plant Reach) which extend from the Beach Park to the Waste Water Treatment Plant. This area can be managed for immediate improvements to fish habitat and production. Salmon currently use portions of this area, and with minor improvements and creation of effective fish passage at Marine View Drive, increased spawning and improved rearing success could be anticipated in the short term.

Zone 2 would include the reaches between the WWTP and South 200th Avenue (the Ravine Reach, lower portions of the Plateau Reach). This zone is potentially capable of providing habitat for both salmon and trout, but is currently degraded due to high flows and excessive erosion. Early efforts in zone 2 would focus on improving habitat through creation of pools and establishment of a stream-bed more suited to salmon. Subsequent phases would then focus on removing the remaining barriers to migration in order to allow salmon access the rehabilitated habitat in the Ravine Reach.

Zone 3 lies above South 200th Street and includes the golf course, Northwest Ponds, Bow Lake and the upper watershed tributary to these water bodies. This zone is proposed to receive enhancement for water quality improvements and improvements to resident fish only. No long term effort to bring migratory salmon to this area is recommended. Zone 3 currently has little habitat value beyond the golf course, where most of the drainages are confined to pipe systems. Zone 3 is also noted for substantial water quality issues during summer months, with both temperature and dissolved oxygen problems above the confluence of the East and West Forks of Des Moines Creek. Several barriers to fish passage also make access to this area by migrating fish a challenge.

Even if the water quality, habitat and passage issues were addressed, bringing salmon to the golf course area would also create a safety issue since this area lies directly under the flight path for SeaTac Airport. Spawned out salmon tend to bring in large numbers of avian scavengers and predators, most notably eagles. There are significant safety issues associated with attracting large birds to the proximity of the flight path.

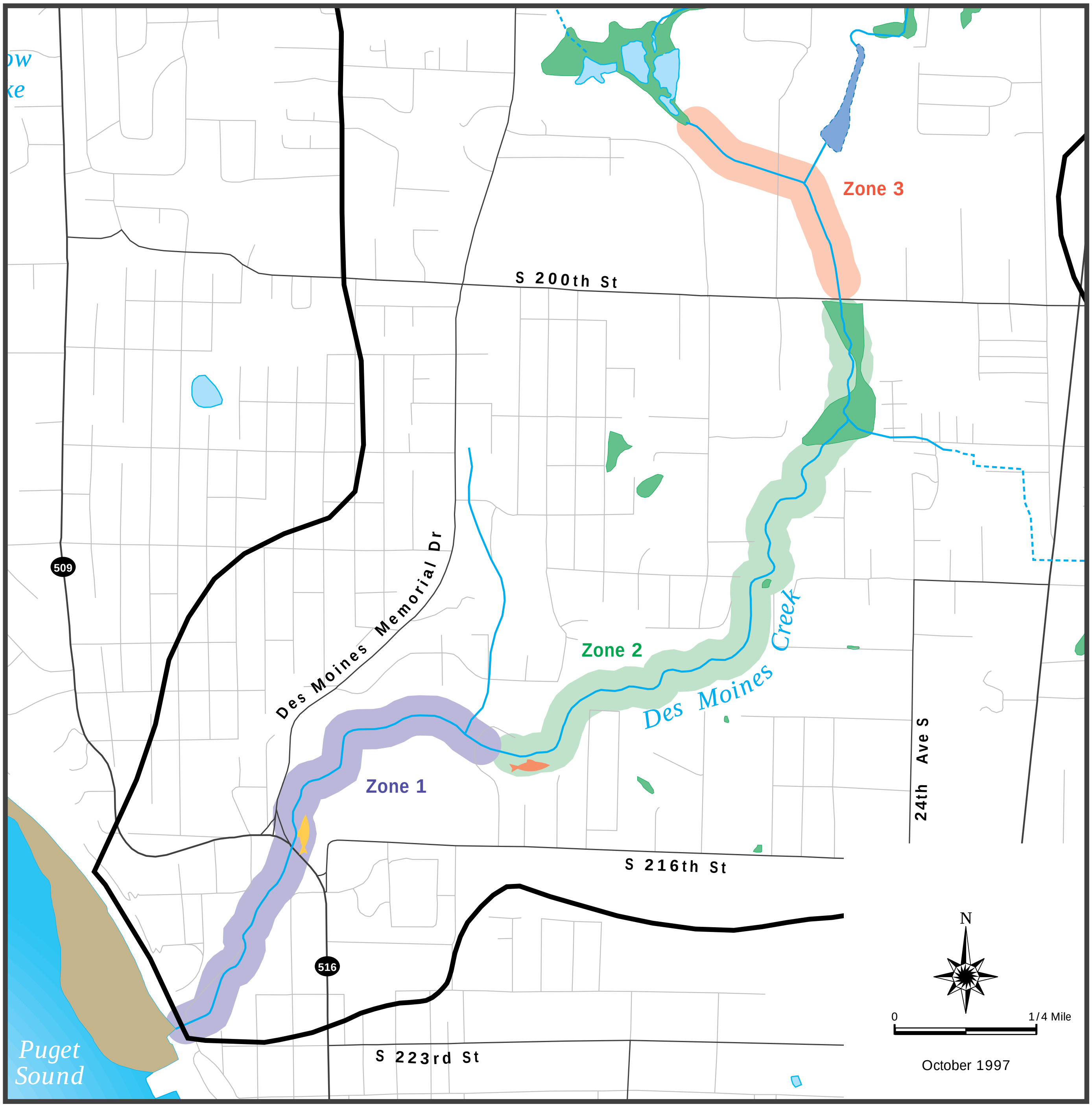

Figure 6-2

DES MOINES CREEK BASIN

Proposed Fish Management Actions

Zone 1
Immediate Salmon Use
Habitat Improvements (Phase I & II)
Passage Improvements (Phase I)

Zone 2
Habitat Stabilization (Phase I)
Passage Improvements (Phase II)
Habitat Improvements (Phase II)
Future Salmon Use (Phase II)

Zone 3
Continuing Resident Trout Use (Phase I)
Habitat Improvements (Phase I)
West Fork Channel Improvements (Phase I)

Fish Passage Improvement at Marine View Drive
Fish Passage Improvement at Midway Treatment Plant
Basin Boundary
Stream
Piped Stream
Lake
Wetland
R/D Facility
Shoreline

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Fish Management Goals

	Zone 1 (Beach Park and Sewer Plant Reach)	Zone 2 (Ravine Reach and lower Plateau Reach)	Zone 3 (upper Plateau Reach and urbanized upper watershed)
Phase I	Passage and in-stream habitat improvements. Salmon use anticipated.	Habitat stabilization and in-stream habitat rehabilitation. No salmon use anticipated	Water quality improvements and habitat improvements for resident trout.
Phase II (in 5-10 years)	Additional habitat improvements, maintenance. Salmon use anticipated.	Passage and in-stream habitat improvements Salmon use anticipated	Maintenance. Resident trout use anticipated.
Phase III (in 10-20 years)	Maintenance. Salmon use anticipated.	Additional habitat improvements, maintenance. Salmon use anticipated.	Maintenance. Resident trout use anticipated.

6.2.2 Riparian Habitat Protection and Improvements

Numerous previous studies have shown that the riparian zone is critical to the overall health of stream systems. Riparian vegetation provides critical shading of the stream, limiting both temperature and dissolved oxygen impacts during the critical hot summer months. Riparian vegetation helps stabilize banks, provides a source for critically needed woody debris which adds physical structure to the stream, and serves as a source of insects and organic material which serve as sources of food to the stream ecosystem.

Des Moines Creek is fortunate in that the riparian zone below South 200th Avenue is still predominantly undeveloped. Protection and enhancement of this riparian corridor is a critical component of improving the long-term health prospects of Des Moines Creek. Jurisdictions with land use control should protect a minimum 100 feet riparian zone on each bank (minimum 200 foot wide riparian corridor) where development is prohibited, from South 200th Avenue to the mouth of Des Moines Creek. Riparian corridor protection is most critical in the wetland reach immediately below South 200th Street, where the wetland is currently providing substantial water quality benefits and some detention benefit to the stream. Existing regulations in SeaTac call for 50-foot buffers due to the previously unconfirmed presence of salmonids. Des Moines regulations call for 100-foot buffers. The existing service road, the existing wastewater treatment plant, the proposed recreational trail, and on-going park activities in Des Moines Creek Beach Park should be the only exceptions to this protection zone and additional encroachments should be minimized to the maximum extent possible.

Riparian zone rehabilitation and bank planting should occur throughout the watershed. Bank repairs should include bio-engineering elements whenever possible to minimize further maintenance needs and to reestablish a more natural bank condition. Riparian plantings are most immediately needed in portions of the Beach Park which are being overrun with blackberries, and in the ravine reach were erosion and proximity of the service road have impacted the riparian zone. In addition to bank plantings, a program of conifer undergrowth plantings should be established throughout the area below South 200th Street, to gradually convert the existing deciduous forest back into native conifers. A coniferous forest provides better habitat for native wildlife, provides better cover for the stream in both the summer and the winter, the woody debris from conifers lasts substantially longer as stream habitat structures, and the coniferous forest is more resistant to damage from storms.

Substantial improvements to the effectiveness of the riparian zone vegetation should also be made on the Tyee Golf Course. The Golf Course is currently the location of water quality concerns due to lack of shading and low velocities. Additional riparian vegetation, especially on the south and west banks, would help limit temperature impacts during summer months. Establishment of a more forested riparian buffer is also believed to be an effective measure for limiting the stream's attraction to the larger birds which produce safety concerns in the aircraft operation area above the golf course. Careful selection of plants is needed to provide shading without increasing bird use and exacerbating safety issues.

While a 100-foot buffer is not practical in this location due to conflicts with existing uses, improvements to the existing situation could be made with little disruption to the ongoing recreational activities. A cooperative arrangement with the Tyee Golf Course should be developed a maintenance plan that limits riparian disturbances while still promoting safe golfing. Vegetation plantings should be selected to match their adult height to the location on the golf course, with short plantings made where fairways cross the stream and taller plants where play does not cross the stream.

6.2.3 Additional Habitat Improvements

Improving the flow regime in Des Moines Creek will not of itself suffice to provide for a healthy stream environment. Flows are the primary driver behind many of the forces that shape a stream: erosion and downcutting of the channel and its banks, transport of nutrients and sediment from farther upstream, and other important processes. In a stream as degraded as Des Moines Creek, however, flow improvement must be coupled with in-stream stabilization and habitat measures in order to be effective at restoring stability. A program of management measures within the stream and its riparian corridor is recommended to supplement the flow reduction proposals.

For the purposes of determining a suitable and cost-effective approach to protecting the Des Moines Creek stream channel, the stream has been divided into five principal reaches. Each of these reaches has different characteristics from its neighbors, and provides a different set of functions to the overall stream habitat of Des Moines Creek. The overall management strategy recommended in this plan focuses on using the upper reaches primarily to afford protection to the downstream reaches through provision of flood storage, both constructed and natural, and a stable environment that can trap fine sediments and avoid massive future erosion.

Implementing projects within the stream should be an adaptive process. A comprehensive set of treatments should be applied simultaneously to the first phase of the combined detention/bypass alternative. After initial construction, follow-up monitoring should be undertaken as described elsewhere in this report, to ensure that the strategies used in Phase I are effective. Based on the results of that monitoring, additional measures may be necessary in Phases II and III as well. Although the techniques for the second and third phases are not specified here. Thus, project recommendations and costs for this management program are for Phase I activities only.

The individual reaches of Des Moines Creek are listed below, along with the objectives for management, the recommended measures, and the estimated Phase I costs:

(1) <u>The Golf Course Reach</u> (RM 2.15 to 2.35 - see Figure 1.2 for RM locations)

Management objectives: Maintain and enhance the natural flood storage. If major stream reconstruction is necessary to relieve the golf course flooding problem in the R/D pond area, use this opportunity to lengthen the channel and create stream diversity.

Recommendations: Phase I recommendations depend on whether the combined detention/bypass project includes the provision for reconstruction of this stream reach as part of reducing flooding of the Tyee Valley Golf Course. If so, then this reconstructed reach should be enhanced by replacing the concrete weirs, reducing the overall stream gradient, and rebuilding the stream with placement of large woody debris complexes to improve channel diversity. If the stream reconstruction option is not chosen, then a minor approach of restoring channel banks that were severely eroded in the February 1996 flood event, and replanting the riparian zone with native vegetation (principally willow cuttings) is recommended.

Estimated cost: Major reconstruction: $130,000 (note that this is included in the total for the combined detention/bypass alternative); Minor stabilization and replanting: $40,000

(2) <u>The Wetland Reach</u> (RM 1.85 to 2.15 - see Figure 1.2 for RM locations)

Management objective: Maintain and enhance the natural flood storage function of the wetland system.

Recommendations: Very limited instream work. The addition of some large trees, woody debris, and habitat snags could be useful, but is not as important as the work described for other stream reaches.

Estimated cost: $10,000

(3) <u>The Ravine Reach</u> (RM 1.0 to 1.85 - see Figure 1.2 for RM locations)

Management objectives: Stabilize the steep channel; provide for channel geometry that can respond positively to predicted flows and reduce risk of bank failures adjacent to sewer line access road. Allow fish passage through any constructed stabilization measures.

Recommendations: Bed stabilization using rock weirs. These should be constructed from large rock and be able to withstand expected flow velocities (2-man rock size is recommended). Weirs should be notched for fish passage and oriented to direct higher stream flows toward the center of the channel. For Phase I, installation of 20 weirs at key locations throughout this reach should suffice to provide substantially improved stream stability.

Estimated cost: $50,000

(4) <u>The Treatment Plant</u> (RM 0.4 to 1.0 - see Figure 1.2 for RM locations)

Management objectives: In Phase I, provide more pool habitat and increased channel complexity. Reduce the risk of bank failures adjacent to the sewer line access road. A possible later phase would be to improve fish passage through the treatment plant fish ladder weirs.

Recommendations: Placement of several types of habitat elements: large woody debris complexes on the outside of bends and/or channel spanning; small rock deflectors; and small groups of fish and turning rocks. These should all be designed both to enhance habitat and to divert high velocity flows away from the access road. The priority sections of the stream for these measures are those where the access road runs adjacent to the stream. Phase I should be intended to begin the habitat enhancement program, with later measures dependent on the results of monitoring. An example program for this reach could include the following measures:

- 4 large woody debris complexes of 4 to 6 logs each;
- 15 rock deflectors, each spanning 40 percent of the channel. Half could be located immediately upstream of the large woody debris complexes; while the other half could be used in areas of high velocities to divert flow away from the bank; and
- 5 groups of fish rocks (3 to 5 rocks per group).

Estimated cost: $130,000

(5) <u>The Park Reach</u> (RM 0.0 to 0.4 - see Figure 1.2 for RM locations)

Management objectives: Provide more pool habitat and increased channel complexity.

Recommendations: Implement similar measures to those described in Reach 4, at approximately 25 percent of the quantities.

Estimated cost: $50,000

The total Phase I cost is estimated at $260,000.

6.3. Water Quality Recommendations

6.3.1. Fecal Coliform Bacteria Reduction

Fecal coliform bacteria may present a health hazard during storm and dry conditions in the Des Moines Creek basin. RNA fingerprinting of fecal coliform strains indicates human/septic contamination as a major source of fecal coliforms, although further sampling is necessary to corroborate this analysis. The recommendations below emphasize known sources. A reduction of fecal contamination will likely result in a reduction of nutrients, as well.

1) **Septic Systems:**

1.1) Develop a clear understanding and set of maps showing sewered and unsewered areas. Work with Midway Sewer District to identify houses within the sewered areas who are not connected to the sanitary sewer. Areas with chronic septic system problems should be connected to sewer lines.

1.2) Work with the Seattle-King County Department of Public Health (SKCDPH) and the Cities to conduct a failure assessment in the sewered (if step 1.1 above shows a significant number of unconnected homes in the sewered areas) and unsewered areas. Conduct the assessment during wet weather conditions. The SKCDPH should evaluate the need for action including requirements for maintenance and inspection programs or more stringent corrective measures consistent with new state regulations (Chapter 246-272 WAC).

1.3) The SKCDPH and the Cities should conduct educational or enforcement programs to encourage better maintenance and regular pumping of septic systems.

1.4) The Cities, King County and the Midway Sewer District should work cooperatively to seek funding or other means to encourage increased level of hookups to the sanitary sewer within sewered areas.

2) **Illicit Connections**

Follow-up and expand the illicit connection survey conducted by the City of Des Moines to investigate the sewage odors. Expand the survey to include unincorporated areas and the other cities. This survey may also help to reduce other problems besides fecal coliforms, such as the “white foam” seen on the creek occasionally.

3) **Waterfowl**

Work to reduce waterfowl on Bow Lake. Discourage feeding of birds by lake residents. While birds are not believed to be a significant source of fecal coliform contamination, they do serve as a substantial source of nutrients, contributing to water quality problems and algae blooms during summer months.

4) **Domestic animals**

Actions for this source include education of pet owners, signage at entry points to the proposed trail along Des Moines Creek, and requiring owners to clean up after their pets.

6.3.2. Roadways

As the area develops, increases in vehicle traffic will be responsible for an ever-increasing portion of the toxic loading to the basin. Source-control techniques would include having less vehicles on the road or redesigning the vehicles to emit fewer toxins. Decreasing traffic by using public transit may be a more feasible option than implementing copper-free brake linings, electric engines and using other less toxic vehicle materials. Because roadways are such a diffuse source with many discharge points, management is difficult and constructed facilities are expensive. It is recommended that when major highways are modified, expanded or newly constructed, their runoff collection systems be designed to include water quality treatment. It is also recommended that the Washington State Department of Transportation (WSDOT), King County and the cities in the basin emphasize actions that reduce nonpoint pollution from roadway runoff and road maintenance activities. This includes retrofitting the existing facilities with pollution treatment Best Management Practices (BMPs) such as biofiltration and wetponds, where feasible. Also included should be maintenance of the existing stormwater conveyance system for water quality control. The Washington State highway runoff regulations require some treatment, but treatment should be included in any water quantity roadway collection system in this basin.

BMP activities that local jurisdictions currently implement and that significantly reduce pollutant loads from roadways, include regular maintenance of catch basins to remove trapped sediments and sweeping of road surfaces.

6.3.3. Development

It is recommended that the cities in this basin adopt the pending update of the King County Surface Water Design Manual. The proposed manual includes a menu of water quality treatment methods for some types of new development, requiring removal of a specified fraction of pollutants through constructed facilities. Single family residences are exempt; however, they can constitute a significant source of pollutants, depending on the lifestyle and practices of the population. Continuous, understandable and targeted educational programs are critical to addressing single family residential source control.

6.3.4. Source Control

Water pollution source control BMPs should be emphasized to reduce or eliminate non-point source pollution and spills. It is much more efficient and cost-effective to contain or prevent pollution at its source than to remove it once it has entered the system. It is strongly recommended that the cities each develop a Stormwater Pollution Prevention Plan (SWPPP), similar to the Plan already developed and implemented by the Port of Seattle, to guide and focus source control efforts. The plans will compel each of the jurisdictions to maintain its role in implementing source control BMPs such as street sweeping, sump cleaning, and proper maintenance of roadside ditches. The SWPPPs would also serve to ensure consistency of efforts between the jurisdictions - the Des Moines Creek Basin Committee should review each city’s initial plan, make recommendations for modification if necessary, and review the plans (and their implementation) on an annual or biannual basis.

As stated in Section 6.3.1, the jurisdictions should collaborate with the Midway Sewer District and the Seattle-King County Department of Public Health to identify and remedy failing septic systems and illicit sewer connections, through further investigation, prioritization, education, incentives, and enforcement.

It is recommended that the Cities and the County work together to implement a business oriented source control program, modeled after the King County Businesses for Clean Water program. The program provides technical assistance to businesses to improve water quality through a non-regulatory approach. Examples include assistance with reduction of waste generating practices, improved outside storage of chemicals, incorporation of source control techniques in new construction such as vehicular wash pads connected to the sewer and covered parking.

Pending the outcome of the Port’s deicing evaluation, actions should be taken to reduce glycol or other pollutants of concern from routine operating practices from entering Des Moines Creek.

In terms of spill control, the Port has a spill control plan which is updated and modified as appropriate. The Cities should also develop spill response plans in cooperation with the local fire departments, WSDOT and other agencies involved in roadway spills on the highways that cross the basin. When retrofitting stormwater conveyance systems in the basin, the feasibility of including spill control BMPs, such as “T” sections in catch basins, should be used to prevent discharge of pollutants into the drainage system. This will require frequent cleaning, at least annually, to remove the accumulated pollutants and sediment. Should the proposed detention/bypass and the flow augmentation facilities be constructed, the existing spill response plan for the area should be revised to the advantage of the opportunities for improved spill control presented by these new facilities.

Finally, it is also recommended that the jurisdictions consider establishment of a formal spill response procedure, possibly supporting a spill response team. Similar teams are utilized in other jurisdictions. In light of the extremely industrial/urban nature of the Des Moines Creek Basin, such a contingent would be highly desirable. Equipment would be purchased and a number of staff from the cities could be trained in appropriate safety, containment, and sampling procedures for minor spills, and notification protocols established for larger/hazardous spill events.

6.3.5. Public Involvement and Education

Public involvement and education is essential to improving basin water quality conditions, because it is a primary means of reaching the growing basin population, especially in highly-developed areas. Increased public education efforts should be focused on influencing people to replace practices that increase nonpoint pollution or harm aquatic habitat with those that enhance drainage system health. Specific examples include reducing harmful household chemicals, regularly maintaining septic systems, and infiltrating roof -runoff. Targeted programs in multifamily residences such as solid waste disposal, recycling, and multi-lingual signs have proven to be effective in other urban basins in the Puget Sound area.

Examples of pubic involvement activities include stream and revegetation projects, storm drain stenciling in languages representative of the local population, interpretive and litter signage and adopt-a-stream programs that include monitoring water quality, fish runs, lake levels, and precipitation. Overall, the educational programs should complement and be linked to other ongoing stormwater activities in the basin, since a knowledgeable public will play an increasingly important role in protecting and restoring Des Moines Creek.

6.3.6. Airport

Pending the outcome of the studies being conducted by the Port as part of its NPDES permit requirements (described under the section“Ongoing Programs”), the results will indicate the impact of the airport runoff on the creek system. These results, including the loading of constituents, wetlands evaluation, and stream and outfall monitoring, should be evaluated within the context of this entire report to determine the relative significance of various sources and consequently, to prioritize actions. It is not possible to adequately or fairly evaluate the role of the airport in the degradation of Des Moines Creek without the results of the above mentioned studies. It is critical to place the Port’s information in context with all the other basin information to evaluate relative significance. The future development levels and proposed highway expansions will also have a significant impact on the water quality.

6.3.7. Bow Lake

The City of SeaTac can participate in the King County Lake Stewardship Program, offered through the Surface Water Management Division. For a small annual fee, technical expertise will be available to conduct lake stewardship workshops, train volunteers to conduct monitoring and answer questions related to the observed conditions. Volunteer monitoring is invaluable in characterizing lake conditions and fosters a stewardship behavior critical to lake health. The information gathered by the volunteers can be the foundation of an educational program for lakeside residents. The City of SeaTac should develop and implement a lake water quality plan to reduce algae blooms and fecal loadings originating in Bow Lake.

6.3.8. Reduce Impervious Area

Increased impervious area is the single largest factor driving future degradation of the Des Moines Creek stream system. Jurisdictions should make every effort to limit the development of new impervious area within their area of control whenever possible. Recent work by the City of Olympia, which focused on reducing the amount of impervious area in new development through changes to development regulations such as road widths and cul-de-sac layout, indicate that impervious area can be reduced without adversely affecting development. The jurisdictions should consider a joint study of existing development regulations to identify opportunities to slow the increase in impervious area within the watershed.

6.4. Implementation Recommendations

6.4.1. Continue Des Moines Creek Basin Committee

The Des Moines Creek Basin Committee is successfully providing a forum where jurisdictions can address trans-boundary water quality, surface water issues, and aquatic habitat issues in a cooperative and mutually beneficial manner. The Committee has already successfully managed the preparation of one of the least expensive and most rapidly completed basin plans yet prepared in King County. Along the way, the Committee has identified opportunities to save substantial amounts of money on projects and sampling efforts, identified opportunities for cooperative efforts benefiting the entire watershed, and begun the process of identifying funding assistance for implementation of recommended projects.

It is recommended that the jurisdictions continue to jointly fund and manage the shared staff in order to continue the Committee's business and to implement recommended projects over the next several years. Consensus-oriented information development and decision making can continue to further the Committee's needs only as long as there is shared staff responding to Committee management and serving the Committee's needs. Development of implementation agreements, management of project design and construction, project permitting, development of project operational guidelines, grant writing, and development of programmatic education and volunteer efforts will all benefit from shared staffing of the Committee over the next several years.

The Basin Committee staff would continue to serve as a point of contact and information sharing for both Committee members and non-committee members. Thus allowing issues to be identified and brought to the Committee for action during the implementation phase of the basin planning effort. Staff availability would also allow the Committee access to shared technical resources for assistance in resolving issues needing analytical and field skills. Shared Committee staff would also be available to facilitate development and implementation of mitigation measures for major projects within the basin.

6.4.2. Jointly Fund And Manage Implementation Projects

The Basin Committee's success to date has been due in large amount to the shared funding and management of the studies and efforts taken to date. Agreement over joint funding of the development of the Basin Plan was a critical step in the evolution of the Basin Committee as an effective team focusing on addressing the needs of Des Moines Creek.

Joint funding and management of implementation projects and programs is strongly recommended. Recommended implementation measures are projects and programs which benefit all of the jurisdictions of the basin. By jointly funding and managing these efforts, the jurisdictions reaffirm their commitment to cooperative problem solving and collective action. Joint funding allows development of more effective programs, access to more sophisticated technical assistance, and the realization of benefits of scale when performing basin-wide programmatic efforts.

Joint funding and management of projects and programs also helps to minimize permitting issues and controversy surrounding implementation projects by indicating broad based support of the proposed projects to permitting agencies.

6.4.3. Initiate a Monitoring Program

The development of a thoughtful and cost-effective monitoring program is an important component to the successful implementation of the proposed projects, and for improving the health of Des Moines Creek. Monitoring is critical for documenting the success of previous efforts in reducing existing problems, for identifying emerging problems, for determining when Phase II and Phase III projects should be implemented, and for determining the effectiveness of Phase I projects in attaining their goals.

Two general types of monitoring actions are needed. Some parameters are subject to frequent and substantial change and can produce serious impacts to the stream system in a short period of time, such as dissolved oxygen levels or temperature changes. These parameters should be monitored on a continuous basis, as some of them currently are. Other parameters change slowly, over much longer periods, and are most effectively monitored by a more periodic effort such as once a year or once every five years.

Development of the specific monitoring program, identifying both continuous and periodic monitoring needs, locations, monitoring and analysis protocols should occur as one of the first implementation agreements developed under this plan. Development of the monitoring program should take advantage of potential cost savings which occur as a result of existing monitoring activities already occurring in the watershed. Standardization of monitoring protocols and data sharing should be prominent components of a watershed monitoring program.

Specific monitoring needs include:

Continuous stream flow monitoring.

- to identify critical low-flow periods when the flow augmentation facility should be operated,
- to determine the effectiveness of constructed facilities,
- to allow more accurate setting of outlet controls, and
- to create a longer data record for hydrologic modeling.

Regular water quality monitoring

- to identify critical periods when the proposed flow augmentation facility should be operated to protect the lower reaches of the stream against temperature or dissolved oxygen problems,
- to determine the effectiveness of existing and proposed efforts in maintaining water quality downstream of South 200th Street at sufficient levels to support healthy fish populations,
- to track the effectiveness of efforts to reduce fecal coliform contamination in the stream.

Periodic land use/land cover analysis (performed approximately every five years)

- to determine the approximate level of developed impervious area within the basin,
- Growth in impervious area is one of the principle indicators for triggering Phase II and Phase III.

Periodic survey of the stream channel

- to ascertain the rate of erosion, and
- to determine the effectiveness of capital and bank stabilization projects in reducing erosion.

Periodic habitat surveys

- to ascertain the effectiveness of capital and bank stabilization projects in improving the in-stream habitat,
- to ensure the implementation and effectiveness of capital projects aimed at habitat protection and restoration,
- to address the fish management goals outlined in Section 6.2.1 of this document,
- with well-defined benchmarks to quantify increments of success, such as target values of the PHABSIM habitat model, and
- include provisions for baseline monitoring to determine pre-implementation conditions.

The monitoring program should be sponsored by the Basin Committee so that data produced will be generally accepted. There should be a shared agreement on what should be monitored by whom, why it is being monitored, and what actions should be triggered by specific results. Sponsorship by only one of the jurisdictions could produce concerns that the information might be potentially skewed by agendas other than stream improvement.

6.4.4 Continue Involving Other Parties

Efforts by the Committee to facilitate communication between Committee members and other parties interested in the basin have proven to be one of the keys to the successes accomplished to date. Cooperation between Committee members, the Tyee Golf Course, and the Midway Sewer District has allowed the development of a recommended CIP plan resulting in benefits to all of these parties.

Future successes will depend on increased involvement of other parties with interests in the watershed. Education, public involvement and habitat improvement efforts will all involve numerous parties such as businesses, schools, youth groups, and service clubs. Development of close relationships between the Committee and those groups that are focused on stream protection and rehabilitation, such as the Des Moines Chapter of Trout Unlimited and the Puget Soundkeeper Alliance, will encourage broader public involvement, more successful implementation, and substantial cost savings.

6.4.5. Start a Basin-Wide Programmatic Effort

Long term effectiveness in improving water quality in Des Moines Creek will require effective programmatic efforts focused on reducing nonpoint source pollution. Specific programs could include development of a business outreach and assistance program, development of a program to address fecal coliform contamination issues in the Creek, and development of a volunteer assistance effort. Substantial energy and enthusiasm for volunteer efforts exists within the basin, but it is currently difficult to harness due to lack of available staff for development and coordination of volunteer events and provision of minor technical assistance. Provision of staffing for volunteer coordination would likely allow cost savings for a substantial portion of the education, public involvement, and minor habitat improvement efforts recommended.

6.4.6. Revise Spill Response Plan

The implementation of recommended CIP projects, which include detention facilities, bypass facilities, and flow augmentation facilities will create the opportunity to provide a substantially greater level of protection to the Creek from inadvertent spills of hazardous material in the upper basin than presently exists. A cooperative inter-jurisdictional effort should be made to include spill response considerations when designing detention/bypass and flow augmentation facilities. The existing spill response plan for the area should be updated to include changes to the drainage system and the new opportunities presented by the recommended CIP projects.

Table 6.1 Proposed Responses to Initial Problem Prioritization

	Problem	Response
Regional High Priority	Fish passage blocked at Marine View Drive	Recommend supporting Des Moines project for replacement of culvert with bridge
	Flooding in Des Moines Park	Planned removal of buildings will eliminate most damage. Proposed detention/bypass will limit high flows. Access bridge flooding minimized by construction of new bridge.
	High temperatures during summer	Riparian vegetation improvements on Golf Course and proposed flow augmentation facility will reduce frequency and severity of temperature problems.
	Too much riffle habitat, not enough pools	Proposed habitat improvements and habitat rehabilitation to increase number of pools.
	No gravel in streambed in ravine	Proposed habitat rehabilitation in ravine to increase number of pools and gravel retention.
	Severe bank erosion at 2 locations below sewer plant	Both have been repaired by Midway Sewer District using bio-stabilization methods.
	Episodic spills	Recommend cities and Port participate in development of spill response plan for basin. Airport has existing spill response plan.
	Tyee Golf course temperature and flooding	Temperature problems addressed through riparian habitat improvements and flow augmentation. Flooding addressed through channel regrading and proposed bypass facility.
	Tyee Pond outlet improvements	Should occur as part of project design for proposed detention/bypass facility.
	Fine sediment in gravel, at Beach Park	Proposed detention/bypass facility would reduce erosion by 75%, reducing sediment loads to the stream.
	Large slide in ravine	Response expected to occur as part of habitat rehabilitation in phase I
	High fecal coliform levels	Preliminary information indicates human origin. Recommend follow-up studies to identify septic system locations and initiate maintenance or replacement program.
	Periodic elevated levels of BOD and ammonia	Further investigations indicate ammonia not a problem. BOD loading in airport outfalls being addressed through POS Stormwater Pollution Prevention Plan.
Regional Moderate Priority	Debris jams on plateau reach	Response expected to occur as part of habitat rehabilitation in phase I
	Fish passage at sewer plant ineffective	Response expected to occur as part of habitat rehabilitation in phase II
	Rock cascade creating possible fish blockage	Response expected to occur as part of habitat rehabilitation in phase II
	Intermittent erosion of rip-rap sections	Response expected to occur as part of habitat rehabilitation in phase I
	White foam from unknown source	Further investigations needed to identify source of foam. First appears above S. 200th St. Origin unknown.
	Severe bank erosion at 3 places in ravine	Have been repaired by Midway Sewer District using bio-stabilization techniques.
	Local bank erosion in ravine	Response expected to occur as part of habitat rehabilitation in phase I
	Sediment deposition in delta	Proposed detention/bypass facility would reduce erosion by 75%, reducing sediment loads to the stream.
Regional Low Priority	Excessive braiding of channel below sewer plant	Response expected to occur as part of habitat improvements in phase I.
	Bow Lake storage outlet improvements	Recommended improvements included as part of phase I.
	Slides above and below Marine View Drive	Response expected to occur as part of habitat rehabilitation in phase I. Conifer undergrowth planting projects initiated to improve forest habitat and stabilize hillsides.
	Downed trees below sewer plant	No action needed along stream.
	Concrete weirs creating fish blockage on golf course	Weirs crucial to maintaining dissolved oxygen levels. Fish management plan recommends against use of golf course by migratory salmonids, so passage improvements not needed in this area.
	Eroded trail crossing in ravine	Response expected to occur as part of habitat rehabilitation in phase I
	Braided reach w/ flanking erosion around debris jams	Response expected to occur as part of habitat rehabilitation in phase I
	High metal concentrations in water	Water quality Best Management Practices recommended.
Local	Executel Pond seepage problems	Local problem, not addressed.
	Trailer park and road flooding	Local problem, not addressed.
	Stream bank erosion in Des Moines Beach Park	City of Des Moines repairing using bio-stabilization.
	Water quality impacts from road runoff	Water quality Best Management Practices recommended.
	Undersized pipe causing flooding on 28th Ave S.	Local problem, not addressed.
	Sheet flow flooding near 7th S. and S. 216th	Local problem, not addressed.
	Flooding on S. 188th	Local problem, not addressed.
	Side gully erosion at RM 1.35	City of Des Moines drainage improvements.
	Side gully erosion at RM 0.28	City of Des Moines drainage improvements.
	Side gully erosion at RM 1.12	City of Des Moines drainage improvements.

APPENDIX A - HYDROLOGIC MODELING

Modeling as an Analytic Tool in Watershed Planning

The Des Moines Creek Basin Plan utilizes two different types of computer models: a hydrologic model and a spreadsheet model. A hydrologic model was developed that continuously simulates streamflow throughout the basin over extended periods that are only limited by the availability of rainfall records. This study used one of the more sophisticated models known as HSPF (Hydrologic Simulation Program - Fortran) which allows the user to analyze a wide variety of existing and future conditions. The basin plan also utilizes a spreadsheet-based pollutant loading model. The model calculates the annual pollutant loadings that can be expected to wash off the different sub-basins in the watershed. Both of these models are described in more detail in the following sections.

Hydrologic Modeling Analysis

Hydrologic Modeling Study of the Des Moines Creek Basin

A quantitative analysis of storm runoff and stream flow was conducted using the HSPF model (EPA, 1992). The purpose of this modeling analysis was to extrapolate spatially and temporally limited stream flow data into a functionally complete set of flow databases from which statistics such as flood frequency, flow erosivity, and low-flow frequency could easily be extracted for locations of interest throughout the Des Moines Creek drainage system. Nine different flow databases were developed to represent flow conditions at 21 basin locations under pre-urbanized conditions, current conditions, and under seven different future build-out scenarios. A comparison of statistics from each of these databases can provide a wealth of information including, but not limited to, the following:

- A description of the flooding, erosional, and low-flow characteristics throughout the basin.
- Comparison of the contributions of different sub-areas to flood hydrographs in the mainstem of the creek.
- Determination of flood attenuation by ponds, wetlands, culverts, and other elements of the drainage system.
- Assessment of the impact of current levels of urbanization on flood peaks, erosive flows and other flow characteristics.
- Determination of changes in flow conditions resulting from realization of different levels of future land development and urbanization.
- Assessment of flow benefits of different levels of drainage controls to be installed by future land development projects.
- Evaluation of the benefits of regional drainage projects to mitigate impacts to drainage system caused by both current and future levels of urbanization.

Development and Application of the Hydrologic Model

The hydrologic modeling study involved five sequential steps: model configuration, model calibration, flow simulations, analysis of current hydrologic conditions, and analysis of conditions for alternative future scenarios. Configuration is the process by which the key characteristics of the basin such as surface area, land use, soils, and drainage features were represented in the model. The final products of the configuration phase are the definition of hydrologic response units (HRUs), the assignment of different acreages of the HRUs to sub-basin areas (or catchments), and the mathematical description and linkage of the drainage network elements to which each of the catchments supply runoff. In HSPF models, HRUs are made up of impervious and pervious land types known as IMPLNDs and PERLNDs. IMPLNDs represent impervious surfaces and a limited number of PERLNDs represent the dominant soil and vegetation combinations found in the basin.

Phase I - Model Configuration

The HSPF Model developed for this study is the most recent in a series of models that have been developed to represent hydrologic conditions in the basin for various purposes. Its most immediate predecessor was an HSPF model developed by Montgomery Water Group (MWG, 1995). The MWG model in turn was based on a TR-20 model developed as a design tool for the Tyee Regional Pond (KC-SWM, 1989). The current KC-HSPF model represents a modification and enhancement of the MWG HSPF model. The most obvious change to the MWG model was to enlarge the model to include the entire Des Moines Creek basin, adding the lower 1.5 square miles of the basin that lie within the City of Des Moines. Additionally, on the basis of field observations numerous changes were made to the representation of pipes and channel segments, to catchment soils composition, and to impervious area percentages. Finally, the KC-SWM model was re-recalibrated and changes were made to the hydrologic parameters. However, it should be noted, that these changes made relatively small differences in the flow of simulations. Simulated flows were primarily controlled by the percentage of impervious area assigned to each catchment, secondarily by the degree of hydraulic attenuation provided by storages within the runoff pathway (e.g. Bow Lake, Tyee Pond, and Northwest Ponds), and only to a lesser extent by deviations in parameter values from USGS regional values (Dinicola, 1990). Impervious area was not adjusted as part of the calibration process. Impervious area values were confirmed during this study and were found to be consistent with land use information reflected in the MWG model, the Seattle University (1995) TR-20 report, and updates provided by the Port of Seattle (1996).

Hydrologic Response Unit Definition

Based on land use, surficial geology, and topographic data, the following HRUs were defined to model land runoff in the basin:

Table A.1 HRUs Selected for Des Moines Creek Runoff Modeling

HRU CODE	Land characteristics
TF	Glacial till soils mature forest cover, all slopes
TG	Glacial till soils; grass, shrub, immature forest cover; all slopes
OF	Glacial outwash (highly pervious) soils, mature forest cover, all slopes
OG	Glacial outwash (highly pervious) soils; grass, shrub, immature forest cover; all slopes
SAT	Saturated or wetland soils
IMP	Impervious surfaces (roadways, roofs, runways, etc.) that are directly connected to the drainage network
IWS	Impervious surfaces on airport property that are diverted to the industrial wastewater system (IWS)

Catchment Delineation and HRU Composition

Areal segmentation of the basin into catchments is shown in Figure A.1. In general, contributing areas to prominent features of the drainage system such as lakes, stream reaches, or storm drains determined catchment boundaries. In some cases contributing areas were broken into several catchments of distinct land use.

As shown in the Table A.2, approximately 35 percent of the basin is currently covered with effective impervious surfaces which are by far the dominant factor in the generation of peak discharges in the creek system. Effective impervious surface represents the portion of gross impervious area that is directly connected to the surface drainage system by pipes or other conduits that concentrate runoff. Other impervious surfaces like residential roofs which disperse runoff to lawn surfaces are not counted as effective impervious and are modeled as grass.

Currently, nearly 70 percent of flood-generating effective impervious area within the basin is located in the upper portion of the basin at Sea-Tac Airport and in heavily urbanized areas directly to the east and southeast. Impervious area is approximately evenly distributed between airport and non-airport areas that drain to the west and east branches of the creek in the upper basin. Large surface water storages on these branches, Northwest Ponds and Bow Lake, provide considerable attenuation of peak discharges from both airport and non-airport impervious surfaces.

Representation of the Drainage Network

The third major component of the configuration phase of hydrologic modeling study is schematization and mathematical description of the drainage network and its individual elements including lakes, ponds, wetlands, large pipes, and channel segments. Figure A.2 illustrates how the model discretizes the basin into a finite number of components. The rectangular elements in this figure represent catchment runoff areas that are composed of appropriate acreages of each HRU, while the trapezoidal elements represent the major pipes, ponds, and stream reaches that both store and transport runoff downstream to the basin outlet. Each of these trapezoidal elements is represented in the simulation model by an individual stage, storage, discharge table that approximates its routing (or flow attenuation) characteristics.

Table A.2 Current Conditions - HSPF HRU Composition by Catchment

CATCH. #	CATCHMENT DESCRIPTION	TFM 16 (AC)	OF 34 (AC)	TGM 26 (AC)	OG 44 (AC)	SAT 54 (AC)	IMP 14 (AC)	IWS IMP 14 (AC)	POND/ LAKE (AC)	TOTAL IWS	TOTAL STORM (AC)	TOTAL (AC)
1	**Residential Upstream Of Bow Lk.**	11.2	7.8	144.2	100.2	2.7	148.7		12.6		427.4	427.4
2	**Highway 99 Corridor To Bow Lk.**	1.3	0.9	6.3	4.3	1.3	45.4		0.0		59.6	59.6
3	**Commercial To Bow Lk.**	0.1	0.1	3.9	2.7	0.0	15.6		0.0		22.4	22.4
4	**Res/Comm To E. Branch**	1.1	0.8	33.8	23.5	0.0	68.3		0.0		127.5	127.5
5	**Golf Course To E. Branch**	10.3	7.1	10.5	7.9	3.0	22.0	8.4	0.0	8.4	60.7	69.1
6	**Golf Course To E. Branch**	0.6	0.4	29.2	20.3	0.0	7.4		0.0		58.0	58.0
7	**Upper W. Branch**	0.6	0.6	48.1	48.1	5.4	30.5		0.0		133.2	133.2
8	**Upper W. Branch**	3.1	3.1	19.5	19.5	2.5	37.0		0.0		84.7	84.7
9	**Upper W. Branch**	7.4	7.4	26.2	26.2	0.0	12.2		0.0		79.4	79.4
10	**Golf Course To NW Ponds**	12.8	12.8	7.0	7.0	1.2	2.4		1.1		44.5	44.5
11	**Golf Course To NW Ponds**	1.9	1.9	16.4	16.4	5.8	33.0		7.0		82.4	82.4
12	**Golf Course To W. Branch**	1.7	6.9	7.5	30.0	1.3	0.0		0.3		47.6	47.6
13	**Golf Course To Upper Mainstem**	2.2	9.0	9.5	38.0	0.0	11.3		0.0		70.0	70.0
14	**S. 200th Area To Upper Mainstem**	6.2	25.0	3.8	15.4	0.0	2.8		0.0		53.3	53.3
15	**S. 200th Area To Upper Mainstem**	1.7	2.5	4.8	6.9	0.0	12.9		0.0		28.7	28.7
16	**S. SeaTac To Executel Trib**	7.1	10.3	61.2	88.1	2.0	109.8		0.0		278.6	278.6
17	**S. SeaTac To Executel Trib**	4.5	6.5	4.9	7.1	0.0	13.7		0.0		36.8	36.8
18	**Head Of Mainstem Ravine Area**	10.0	39.9	3.5	14.0	3.8	0.8		0.0		71.9	71.9
19	**North Branch Ravine Trib**	2.2	2.0	72.3	66.7	0.0	37.1		0.0		180.4	180.4
20	**S. SeaTac And Des Moines To Mid. Mainstem**	62.6	43.5	103.5	71.9	1.8	61.9		0.0		345.1	345.1
21	**Des Moines To Lower Mainstem**	31.2	20.8	91.8	61.2	0.0	70.1		0.0		275.0	275.0
22	**Des Moines To Lower Mainstem**	4.9	2.8	59.7	33.6	0.2	28.6		0.0		129.7	129.7
23	**Vicinity Of Airport N. Terminal**	1.1	0.2	27.5	6.2	0.0	118.8	73.6	0.0	73.6	153.8	227.4
24	**Vicinity Of Airport S. Terminal**	0.0	0.0	4.0	2.0	0.0	51.2	70.7	0.0	70.7	57.2	127.9
25	**Vicinity Of Airport Runways**	0.0	0.0	329.9	18.5	0.6	169.7	49.3	1.4	49.3	520.0	569.3
26	**Vicinity Of Airport IWS Plant**	0.0	0.0	25.1	1.4	0.0	9.0	0.9	0.3	0.9	35.7	36.5
27	**Vicinity Of Airport S. Of 188th St.**	0.0	0.0	44.0	2.4	0.9	14.0	0.4	0.0	0.4	61.2	61.6
	TOTALS	186.1	212.3	1198.1	739.4	32.3	1134.2	203.2	22.7	203.2	3525.0	3728.2
	% of BASIN	5%	6%	32%	20%	1%	30%	5%	1%	5%	95%	100%

SYMBOL	HRU DESCRIPTION	SYMBOL	HRU DESCRIPTION
TF	TILL FOREST	SAT	SATURATED SOIL
TG	TILL GRASS (NON-AIRPORT)	IMP	IMPERVIOUS
OF	OUTWASH FOREST	IWS IMP	IMPERVIOUS TO AIRPORT IWS
OG	OUTWASH GRASS (NON-AIRPORT)	POND/LK	NOT AN HRU MODELED AS A REACH

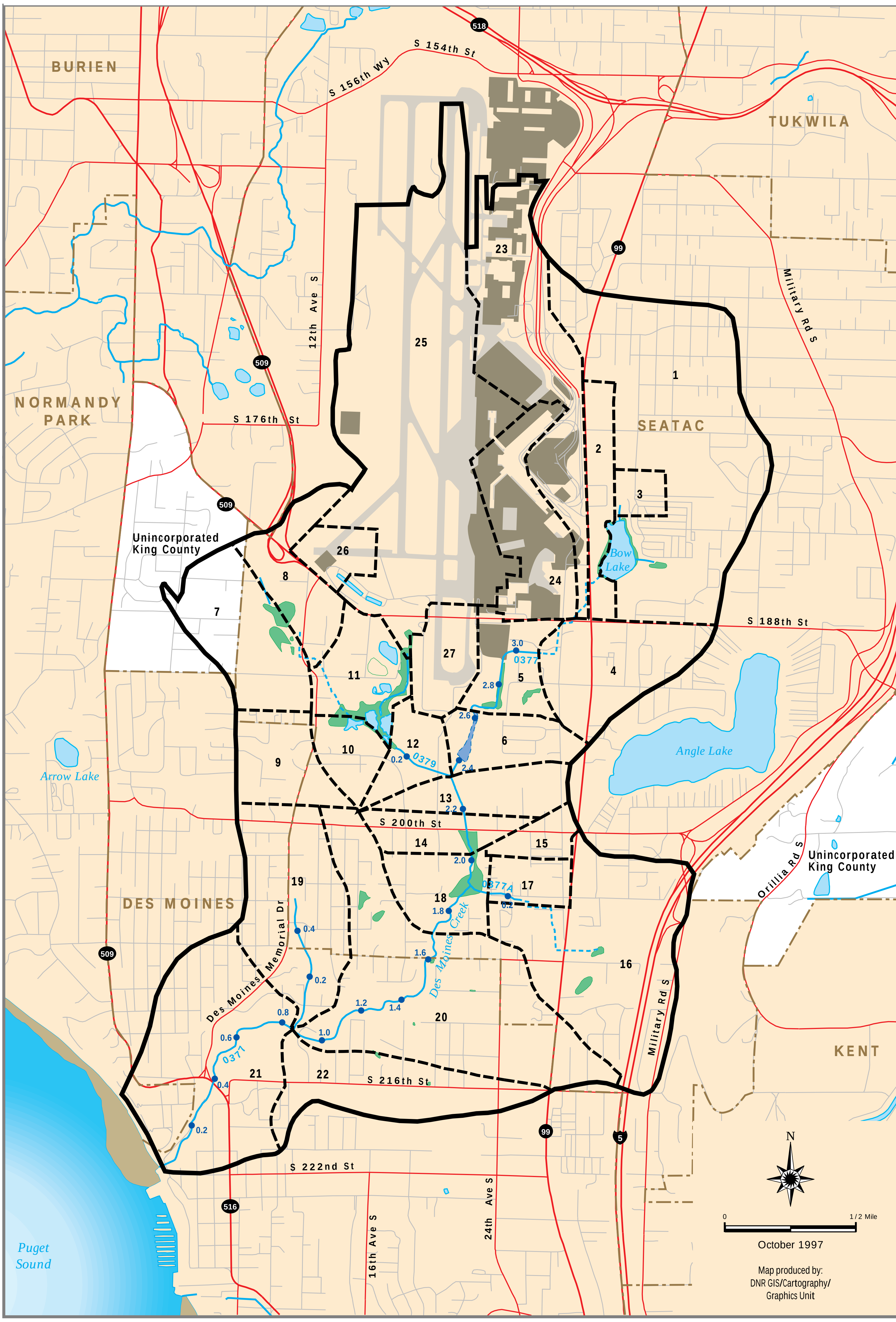


Figure A-1

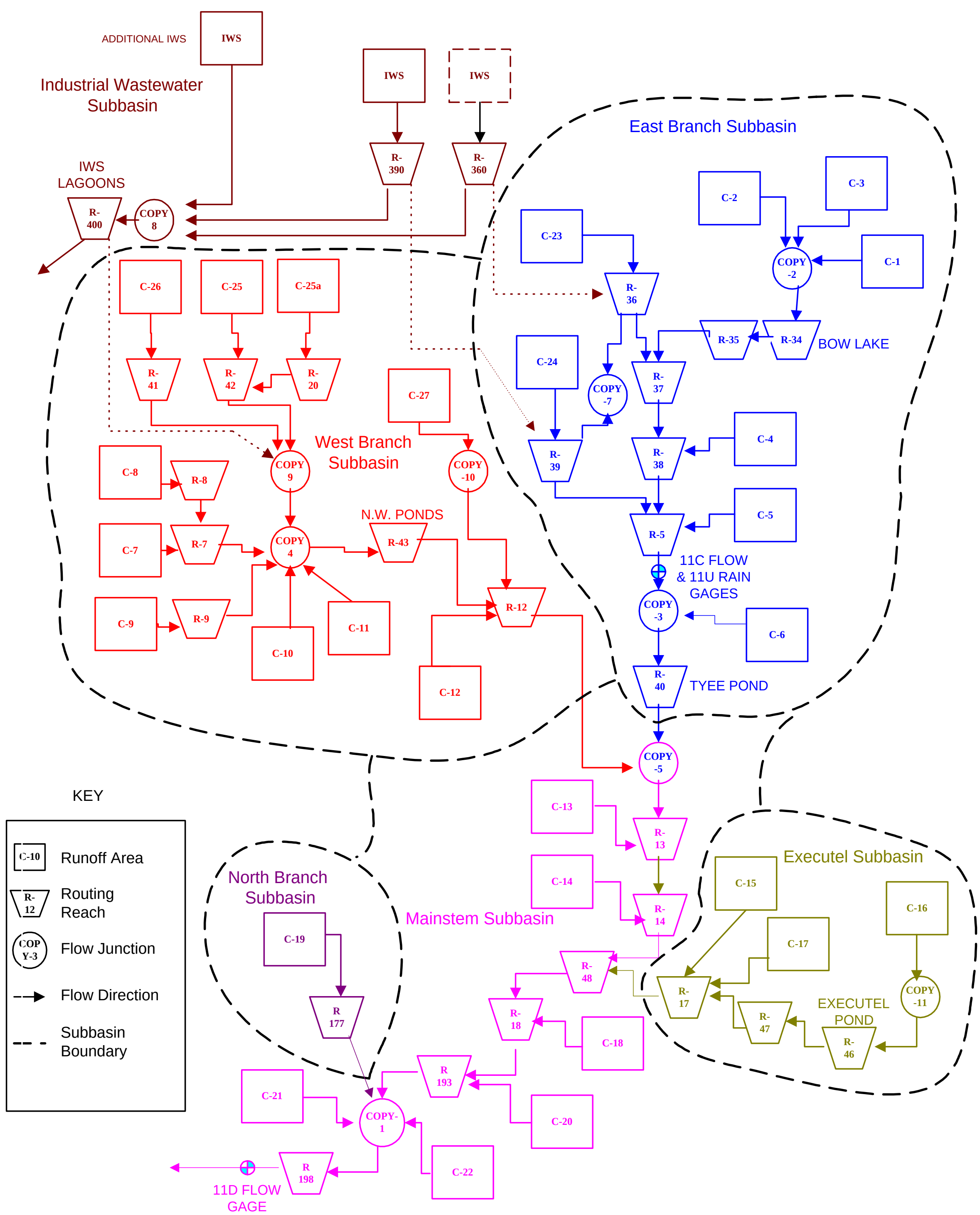
DES MOINES CREEK BASIN
Water Features and Subcatchments

- Basin Boundary
- Subctchment Boundary
- Stream
- Piped Stream
- 0377 Stream Number
- 2.6 River Mile
- Incorporated Area
- Industrial Wastewater System
- Lake
- R/D Facility
- Wetland

Base Map Notes:
All updates register to USGS PLS
Wetland Sources:
Port of Seattle Wetland Mapping, 1995
Map does not include wetland #22
Stream and Pipe Location Sources:
USGS Digital Line Graph
King County Basin Recon Program, 1987
Aerial Photos, 1989
Port of Seattle Field Mapping, 1995
Roadway Sources:
USGS Digital Line Graph
Aerial Photos, 1989
Industrial Wastewater System Source:
Port of Seattle Comprehensive Stormwater and Industrial Wastewater Plan
Contour Lines Source:
USGS Digital Elevation Model
Incorporated Areas Source:
King County GIS coverage

9710DMwf&subsA-1.pdf WG

Figure A.2 Des Moines Creek Watershed Model Schematic



Modeling of IWS System

One aspect of the Des Moines Creek model bears some additional explanation. This is the representation of the Sea-Tac International Airport Industrial Waste System (IWS) that collects runoff from approximately 203 acres of impervious surfaces within the Des Moines Creek topographic basin, and another 50 acres in the Miller Creek basin. Runoff from IWS areas may be contaminated with de-icing chemicals, accidentally spilled fuel, and washwater from airplanes and ground support vehicles (Kennedy/Jenks, 1995). In order to prevent these potential pollutants from entering the stream, a system of pipes collects and conducts drainage from this area to the airport's industrial wastewater plant for treatment and subsequent discharge by pipe directly to Puget Sound. Representation of the IWS system in the model is highly simplified and approximate. As shown at the top of Figure A.2, two routing reaches are used to represent the IWS collection system in the terminal areas in a highly lumped manner. Dotted outflow arrows from these reaches indicate the model's representation of potential overflow of the IWS collection system and resultant discharge of a portion of runoff to the east branch of the creek. In the future, an additional 65.7 acres of IWS impervious surface may be brought on-line as a result of airport improvements (Montgomery Water Group, 1995). This additional area is included in future condition modeling. The model combines the storage available in the three IWS treatment lagoons into a single routing reach also with a potential overflow pathway to Northwest Ponds. In the model, the lagoons are represented as containing a total of 91 acre-feet (29.5 million gallons) of storage. The rate of outflow from these lagoons depends on the treatment capacity of the IWS treatment plant.

Based on an analysis of current capacity and recommendations for future improvements (Kennedy/Jenks, 1995), the following outflow rates (Table A.3) were assumed in the model.

Table A.3 Assumed Outfall Discharge (Treatment) Rates for IWS Treatment System

Scenario	Normal Outflow (mgd)	Peak Outflow (mgd)
Current	2.3	4.0
Future	4.0	6.9

Peak conditions were assumed to occur when half of the storage capacity in IWS lagoons has been filled by inflow. Currently, peak outflow of four million gallons per day (mgd) is obtained by operating the treatment facility at process rate. Proposed expansion of the treatment facility will allow 4 mgd treatment rate under optimal conditions and 6.9 mgd under conditions calling for the maximum process rate.

Phase II - Model Calibration

Model calibration involves the adjustment of parameters to achieve a better fit between simulated and measured streamflow and, by extension, a more realistic and accurate representation of precipitation-runoff processes within the basin. In general, the process involves the following steps: 1) collection/processing/evaluation of contemporaneous rainfall and stream flow data, 2) formulation of a calibration strategy, 3) optimization of model parameters.

Calibration Data

In this study, calibration was performed using over two years of data collected by King County from October 1, 1993 through February 10, 1996. The latter part of this period corresponding to water year 1996 was a record-breaking period for total rainfall, causing several flood peaks in excess of two-year frequency events and one very large event in excess of a ten-year event. The largest of these storms caused severe flood damage throughout the King County but were fortuitous from the point of view of model calibration. The presence of these large storms in the record lends considerable confidence to the flood prediction power of a well-calibrated model.

Available data included 15-minute rainfall totals at Tyee Pond (KC gage 11U) and 15-minute mean stream flows on the east branch, upstream of Tyee Pond (KC gage 11C), as well as on the mainstem of the Creek near its mouth in Des Moines Beach Park (KC gage 11D). Rain gage data were generally considered to be of consistently high quality. For calibration purposes, rainfall measured at 11U was assumed to represent spatially uniform conditions throughout the basin. This is a common assumption in small basin studies, but one that was certainly violated during numerous rain storms over the calibration period. The quality of stream flow data were variable because of dynamic conditions imposed by channel erosion, sediment deposition, organic and other debris, channel overflow, and shifting downstream hydraulic control. In general, accuracy and precision of stream gage measurements decline in proportion to the size of the larger flood discharges. Spatial variability of rainfall and errors in stream gauging are factors precluding a perfect fit between simulated and measured stream flow measurements. The calibration strategy adopted for this study was the following:

1) Begin with HRU regional parameters applicable to the Puget Lowland as defined by Dinicola (1990) which have been found to be reasonable average values.
2) Alter parameters only for till and outwash pervious HRUs because impervious parameters are typically constant from one basin to another within this region, and because wetland (saturated) soil area is too small to affect simulated hydrographs.
3) Judge suitability of parameter values by scatter plot comparisons of storm hydrographs, instantaneous peaks on days with significant rainfall, daily storm runoff volume (mean daily flows), and monthly mean discharge. Augment scatter plot comparisons with full hydrograph comparisons for selected storm events. Reasonable fits in all these categories increases confidence that the model will mimic the entire spectrum of stream conditions of interest including flood peaks, extreme lows, high or low flow durations, seasonal variations, and annual water yield.

4) Use the gage near the basin outlet (11D) as the primary calibration data set, and check the model using the gage on the east branch (11C). This results in a parameter set that represents average conditions over the entire basin.

Summary of Calibration Results

Table A.4 highlights differences between regional average parameter values and values derived for Des Moines Creek basin by optimizing the match between measured and simulated stream flow as outlined above. Large differences between the two sets are indicative of atypical conditions in the Des Moines Creek basin. In this table INFILT is a nominal infiltration rate, DEEPFR is the traction of recharge lost from the surface drainage system by deep percolation or other pathways. INTFW is a parameter that determines the partitioning of runoff between rapid overland flow and slower interflow, and IRC is an interflow recession rate constant.

Table A.4 HSPF Parameter Values

HRU	INFILT (IN/HR)		DEEPFR (-)		INTFW		IRC	
	REG.	D.M.	REG.	D.M.	REG.	D.M.	REG.	D.M.
TF	0.08	**.200**	0.00	**0.70**	6.00	**3.00**	.50	**.25**
TG	0.03	**.075**	0.00	**0.70**	6.00	**3.00**	.50	**.25**
OF	0.80	0.8	0.00	**0.70**	0.0	0.0	-	-
OG	2.00	2.0	0.00	**0.70**	0.0	0.0	-	-

The relatively high till soil infiltration rate (INFILT) and non-zero values for DEEPFR are perhaps most notable. The optimized high INFILT values result from the observation that peak stream flows and storm volumes were consistently lower than for average (regional) basin conditions. Additionally, the total volume of water appearing at the mouth of the creek was smaller than would typically be expected both during the winter runoff period and the dry season- thus resulting in the large values for DEEPFR. This parameter ranges between 0.0 and 1.0 and controls the fraction of infiltrated water that does not discharge through the surface drainage system of the basin or get consumed in evapotranspiration. Instead, it is probably diverted by deep percolation or trans-basin groundwater discharge. In summary, the Des Moines Creek till soils are more infiltrative than average and the basin discharges nearly 30 percent of rainfall as ground water to neighboring basins and/or strata below the drainage system.

INTFW and IRC are parameters that determine the interflow response of till soil areas. Interflow represents shallow subsurface discharge to creeks along the interface between the upper, pervious root layer and the basal till below. Interflow plays a role in determining the slope of hydrograph recessions in the few hours immediately following rainfall. The INTFW and IRC parameters for the Des Moines Creek model result from the observed 'flashy' character of storm runoff in which flows rise and recede very quickly. This suggests a smaller interflow volume and a more rapid interflow recession than is typically observed for till soil areas.

Gauged and simulated total discharge over the calibration period match within three percent with minor over-estimation during low flow periods. Figures A.3 through A.5 document the degree to which simulations match the actual data record. These figures effectively demonstrate that the model is well-calibrated for the basin as a whole and should provide reasonable estimates of the entire spectrum of flow characteristics.

Figures A.6 through A.8 make the same comparisons for the east branch above Tyee Pond (King County gage site 11C). While errors in peak discharge appear generally larger than at site 11D, most points on Figure A.3 lie within 40 percent error bars and show no evidence of bias. Results for daily and monthly means are comparable with those at site 11D.

Phase III - Model Application

The range of applications of the calibrated Des Moines Creek basin HSPF model are practically limitless. The model is in effect a mathematical streamflow generator that only requires rainfall and pan evaporation data to synthesize continuous hydrographs at any location in the schematized drainage network. Additionally, the availability of the long term rainfall record at Sea-Tac airport (hourly rainfall amounts from October 1948 to present) allows the simulation of corresponding long-term flow records from which descriptive hydrologic statistics may be easily extracted. In general, application of the model involves four steps; identification of locations where flow data are required; definition of basin conditions or scenarios to be investigated; model operation on each scenario (i.e. model runs in which flows are synthesized and stored in timeseries databases); and analysis in which flow statistics are extracted from the databases, discussed, and compared.

Identification of Flow Points

Table A.5 lists locations of hydrologic interest within the Des Moines Creek system. For each of these locations, simulated continuous hourly discharges spanning the 46 year period October 1, 1948 through February 2, 1996, have been tabulated within specially formatted Watershed Data Management (WDM) files. As shown in the table, flow data for each location are stored in a separate dataset that is assigned a unique number within the WDM file. The WDM files have been created for several modeling scenarios that represent the basin during past, current, and future stages of land development.

Figure A.4 COMPARISON OF MODELED AND GAGED FLOWS MEAN DAILY DISCHARGE BELOW MARINE VIEW DRIVE (11D)

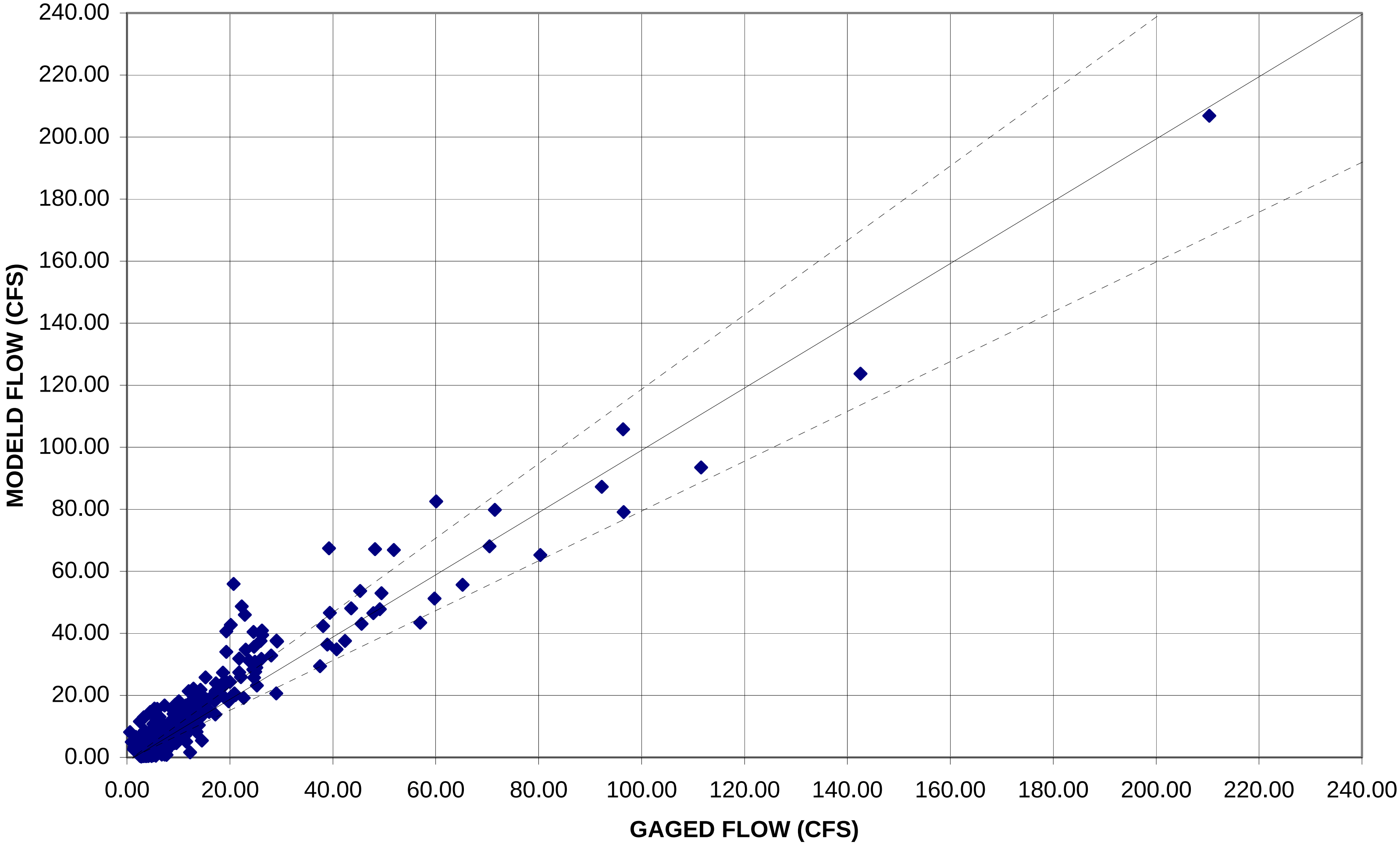


Figure A.5 COMPARISON OF MODELED AND GAGE FLOWS MONTHLY MEAN DISCHARGE BELOW MARINE VIEW DRIVE (11D)

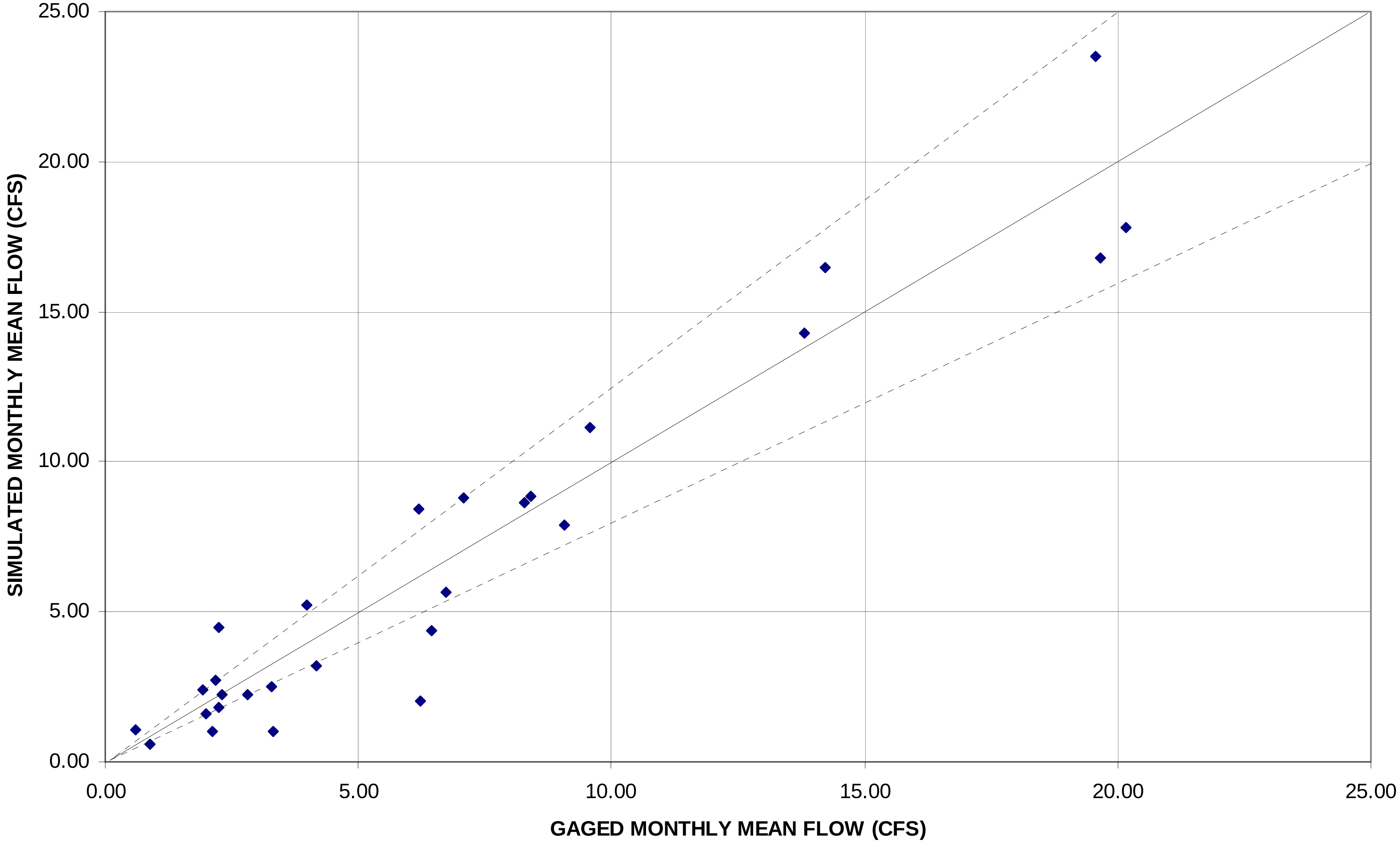


Figure A.6 COMPARISON OF MODELED AND GAGED FLOWS PEAK DISCHARGE UPSTREAM OF TYEE POND (11C)

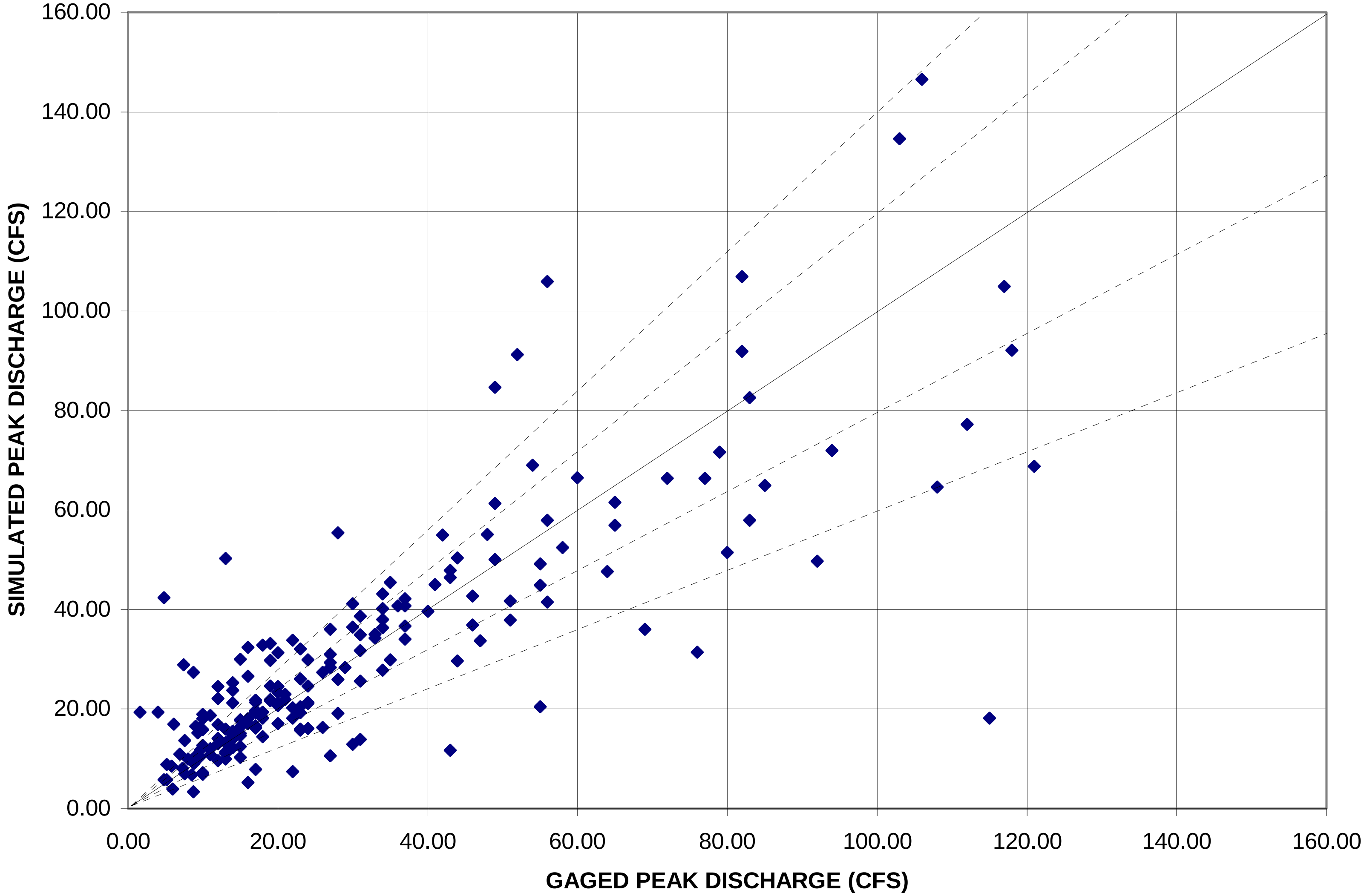


Figure A.7 COMPARISON OF MODELED AND GAGED FLOWS DAILY MEANS ABOVE TYEE POND (11C)

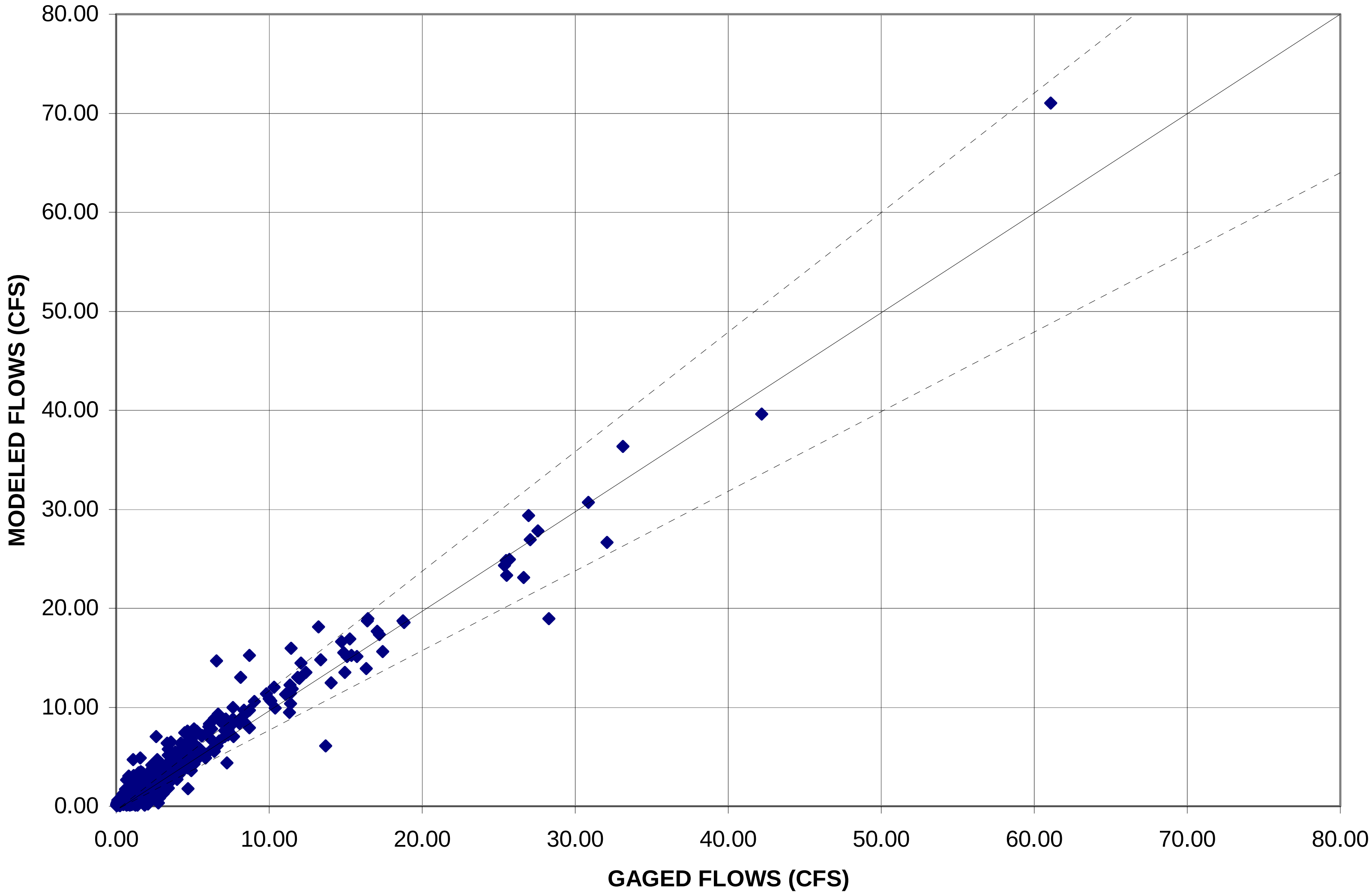


Figure A.8 COMPARISON OF MODEL AND GAGED FLOWS MONTHLY MEAN DISCHARGE UPSTREAM OF TYEE GOLF COURSE (11C)

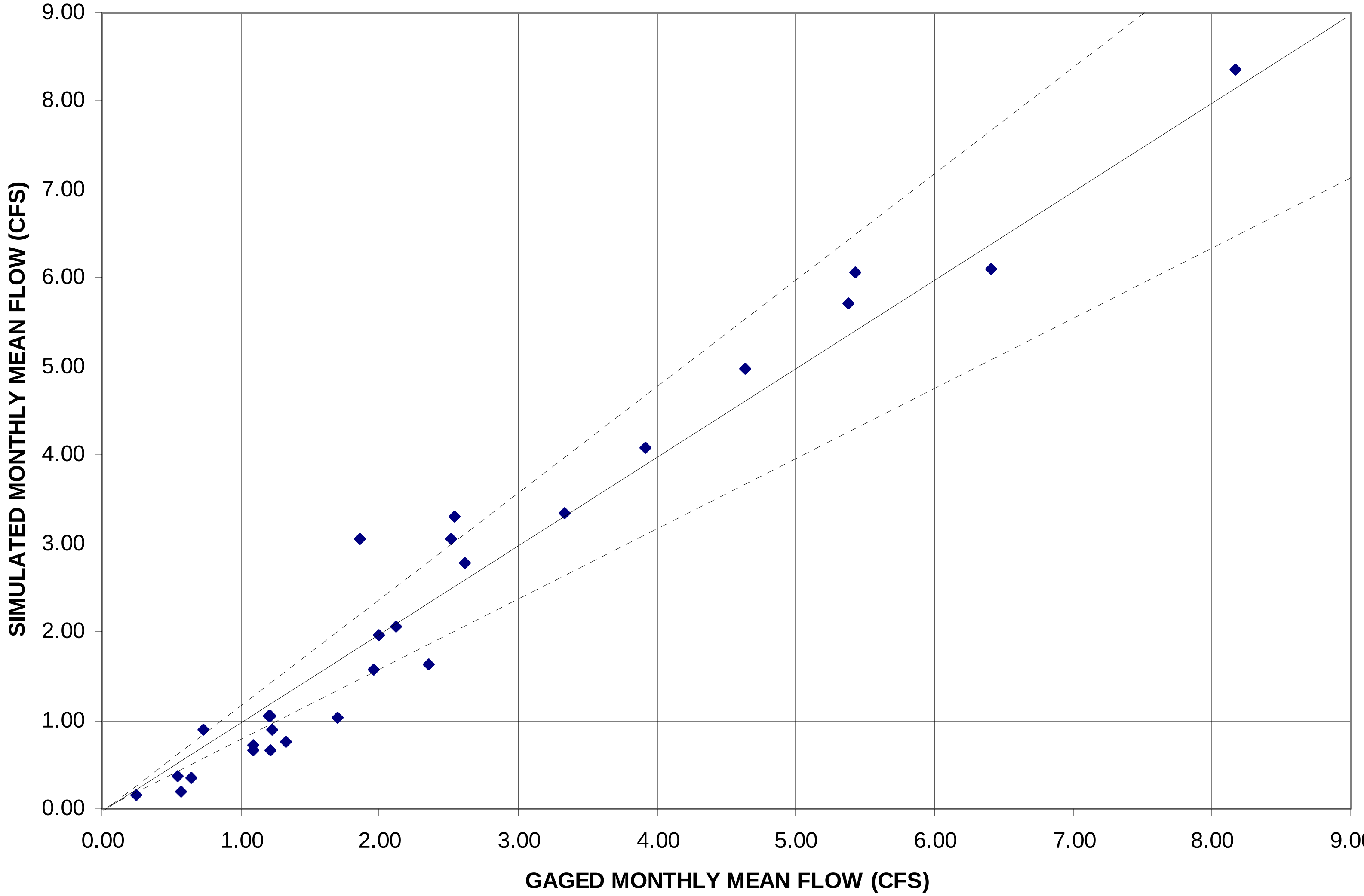


Table A.5. Hydrologic Model Output Locations - see Appendix for datasets.

Flow Location	Symbol	Model Element	Dataset #
EAST BRANCH OF CREEK			
Inflow to Bow Lake	EB1	COPY 2	51
Outflow from Bow Lake	EB2	REACH 34	52
Airport Inflow to Tyee Pond	EB2	COPY 7	53
Total Inflow to Tyee Pond	EB3	COPY 3	54
Outflow from Tyee Pond	EB4	REACH 40	55
INDUSTRIAL WASTE SYSTEM			
Total Inflow to Treatment Lagoons	IWS1	COPY 8	61
IWS Flow to Outfall	IWS2	REACH 400, O1	62
IWS Overflow to Northwest Ponds	IWS3	REACH 400, O2	63
WEST BRANCH OF CREEK			
Airport Inflow to Northwest Ponds	WB1	COPY 9	71
Total Inflow to Northwest Ponds	WB2	COPY 4	72
Outflow from Northwest Ponds	WB3	REACH 43	73
Airport Inflow below Northwest Ponds	WB4	COPY 10	74
LOWER BASIN			
Mainstem above South 200th Street	MS1	COPY 5	81
Inflow to Executel Pond	EX1	COPY 11	91
Outflow from Executel Pond	EX2	REACH 46	92
Executel Tributary to Mainstem	EX3	REACH 17	93
Mainstem at top of Ravine	MS2	REACH 18	82
Mainstem above North Branch Ravine (near Midway Sewer Plant)	MS3	REACH 193	83
North Branch Ravine to Mainstem	NB1	REACH 177	84
Inflow to Marine View Dr. Culvert	MS4	COPY 1	85
Outflow from Marine View Dr. Culvert	MS5	REACH 198	86

Modeling Scenarios

Long term hydrologic simulations were carried out for the purposes of characterizing the flow regime in the drainage system under current land use conditions, determining the level of hydrologic change that has occurred since urbanization began, and investigating the hydrologic impacts of alternative future combinations of commercial and residential zones, construction of large transportation infrastructure projects, and implementation of different drainage mitigation strategies. To these ends, the scenarios summarized in Table A.6 were simulated.

Table A.6 Modeling Scenarios

Scenario Name	Development Level	R/D Standard For New Development	Regional R/D Ponds	Bypass
Forest	None			
Current	Per GIS, etc.	None[1]	None[2]	None[3]
Fut. V.-1	Build out	2-10 standard[4], (SBUH, 1990 manual), 20 percent failure	None[2]	None[3]
Fut. V.-2	Build out, 3rd runway	2-10 standard, (SBUH, 1990 manual), 20 percent failure	None[2]	None[3]
Fut. V.-3	Build out, 3rd runway, SASA,	2-10 standard, (SBUH, 1990 manual), 20 percent failure	None[2]	None[3]
Fut. V.-4	Build out, 3rd runway, SASA, 509	2-10 standard, (SBUH, 1990 manual), 20 percent failure	None[2]	None[3]
Fut. V.-5 (“Maximum Detention”)	Build out, 3rd runway, SASA, 509	Stream protection[5] (KCRTS, 1996 manual), 20 percent failure	Bow Lake (add 25 af), golf course (add 180 af to NWP & 100 af in new pond)	None[3]
Fut. V.-6 (“Combined R/D and Minor Bypass”)	Build out, 3rd runway, SASA, 509	2-10 standard, (SBUH, 1990 manual), 20 percent failure	Bow Lake (add 25-af), golf course (add 180 af to NWP)	24” plus 18”, max 42 cfs capacity
Fut. V.-7 (“Major Bypass”)	Build out, 3rd runway, SASA, 509	2-10 standard, (SBUH, 1990 manual), 20 percent failure	None[2]	54” rcp, 170 cfs capacity[6]

1. No R/D storage explicitly modeled, but some may exist within basin.
2. Currently TYEE regional pond provides about 20 AF storage.
3. None means none additional to IWS which diverts runoff from 112 acres of impervious
4. 1990 2-10 standard results in 0.10 ac-ft of R/D storage per acre of new impervious. This totals to 66 ac- ft over the entire basin for full buildout with all projects.
5. 1996 stream protection standard results in 0.27 ac-ft of R/D storage per acre of new impervious. This totals to 178 acre-feet over the entire basin for full buildout with all projects.
6. Requires construction of new diversion works above South 200th Street and new 54” pipeline to Puget Sound.

Analysis of Current Hydrologic Conditions

Mean Annual Flow and Monthly Hydrographs

Mean monthly rainfall and discharge near the outlet (MS-5) are shown in Figure A.9 for current land use conditions with basin-calibrated parameters, current conditions with regionally typical parameters, and for forested conditions with basin-calibrated parameters. Under current conditions, the basin receives approximately 38 inches of rainfall of which 45 percent is consumed by evaporation, 40 percent discharges to the creek, and 15 percent is lost to deep percolation and trans-basin groundwater discharge. A comparison of the basin-specific and typical hydrographs shows that the basin loses about 25 percent of the rainfall not consumed by evapotranspiration to groundwater leakage consistently throughout the year.

A comparison of current and forested hydrographs shows that mean monthly discharges have increased throughout the year including the summer months, even though gauged flow levels during summer months have been consistently dropping over the years This increase in mean flow during the summer months results from very transient storm discharges that raise creek levels above a very low base flow. These storm spikes did not occur prior to urbanization of the Des Moines Creek basin.

Annual Peaks and Floods

Table A.7 displays Log Pearson Type III peak annual flood frequency quantiles for various locations of interest. The flow exceedance levels are approximate because they are derived from an assumed distribution curve that has been fitted to 47 peak annual data points that are in turn derived from a simulation model. However, these peak annual exceedance flows are still useful as an indicator of how unusual recent floods have been and as comparative values with other simulation scenarios.

Recent Flood Events

The winter of 1995-1996 was a record-breaker for total rainfall in the Des Moines Creek basin and the entire lower Puget Sound region. Heavy storms caused 5 floods between November, 1995 and February, 1996 which exceeded the 2-year peak at the mouth of the creek. The largest of these peaks occurred on November 8, 1995 and was gauged at 261 cfs while the model-simulated flow was 290 cfs. This flood had a recurrence interval of between 10 and 25 years and was similar in magnitude to the flood which occurred on January 9, 1990.

Effectiveness of Basin Storages

Table A.8 shows the percent reduction in flood quantiles between inflows and outflows for the primary basin storages: Bow Lake, Northwest Pond, Tyee Regional Detention Pond, Executel R/D Pond, and the Marine View Drive box culvert. These values do not represent peak flow reductions for specific storm events, but instead indicate the average effectiveness of each water feature.

Among these storages Bow Lake stands out, reducing peaks by more than 50 percent across the range from the 2-year to the 100-year event. This performance results from the lake's relatively large surface area and partially restricted outlet. Tyee Pond, on the other hand, reduces frequent floods only marginally and provides a maximum 27 percent reduction for a 100-year event. Northwest Ponds behave similarly to Bow Lake in that they provide between 25 percent and 30 percent of peak reduction over the entire range of floods. Executel Pond appears to have virtually no effect on flood peaks because storm discharges exit the pond as quickly as they enter it without taking advantage of the minimal available storage. Apparently, the current outlet configuration of Executel Pond only minimally restricts flow, perhaps because of safety concerns, since the pond is dug into a hillslope immediately above a trailer park. The Marine View Drive Culvert appears to provide minor flood attenuation for smaller events but becomes a bit more effective at large infrequent events, providing 17 percent peak flow reduction of the 100-year event.

Figure A.9 COMPARISON OF MONTHLY HYDROGRAPHS DES MOINES CREEK NEAR MOUTH

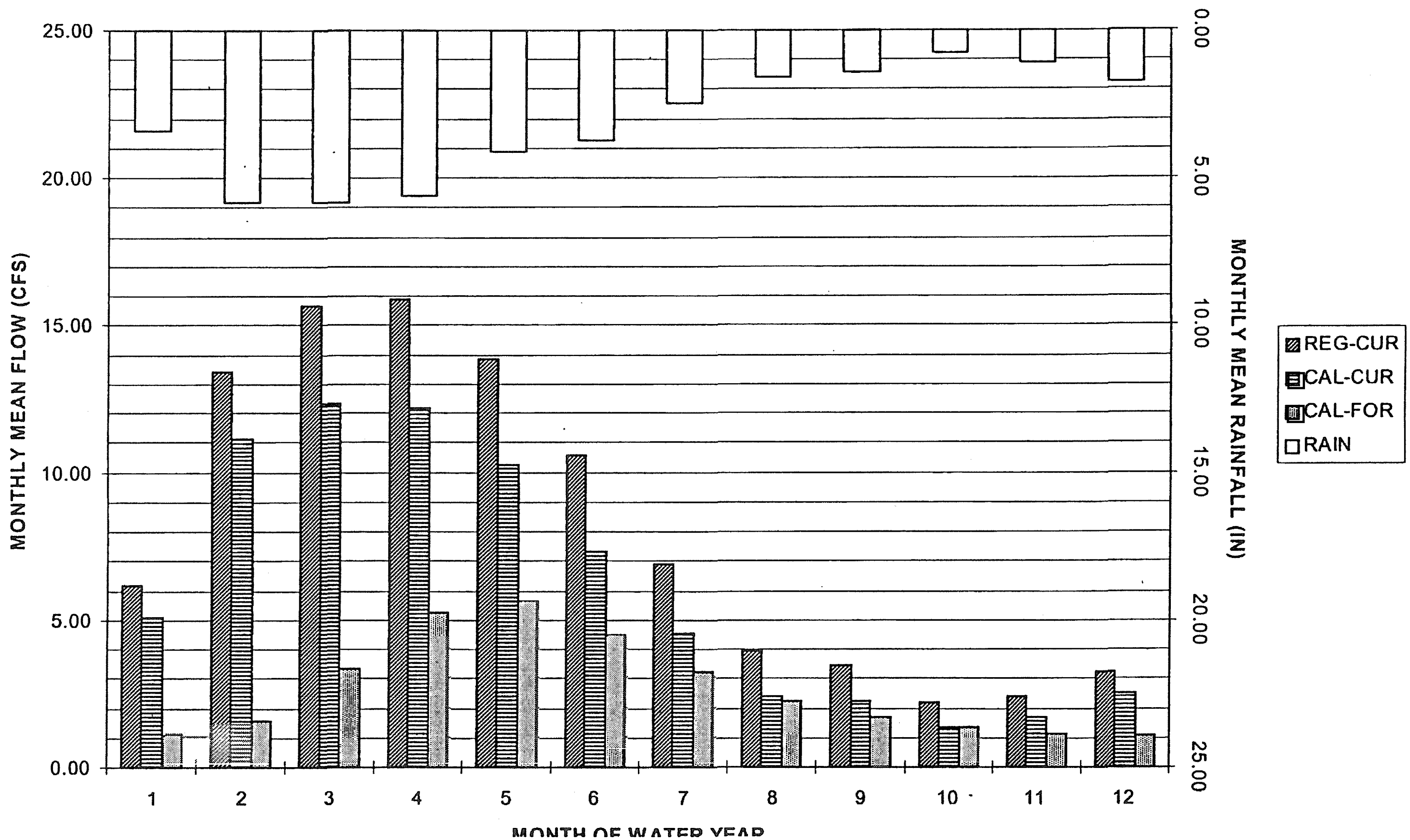


Table A.7 Current Condition Flood Frequencies For Des Moines Creek Basin

		2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
EB1	BOW LK. INFLOW	58	75	86	102	114	127
EB2	BOW LK. OUTFLOW	21	29	35	43	49	55
EB4	TYEE R/D INFLOW	73	93	108	127	142	158
EB5	TYEE R/D OUTFLOW	66	80	89	100	108	116
WB2	NW PONDS INFLOW	59	83	100	123	141	160
WB3	NW PONDS OUTFLOW	42	59	71	89	104	120
MS1	MS ABOVE S. 200 TH.	103	137	161	193	219	246
EX1	EXECUTEL R/D INFLOW	17	22	27	33	38	44
EX2	EXECUTEL R/D OUTFLOW	17	22	27	33	38	44
EX3	EXECUTEL TRIB MOUTH	32	41	48	56	63	70
MS2	MS AT HEAD OF RAVINE	127	169	198	237	268	301
MS3	MS ABOVE N. BRANCH RAVINE	149	199	235	282	320	360
NB1	NORTH BRANCH RAVINE MOUTH	15	21	25	32	38	44
MS4	MS AT INFLOW TO MVD BOX CULVERT	177	238	282	341	388	438
MS5	MS NEAR MOUTH	171	221	255	298	331	364

Table A.8 Percent Attenuation by Existing Major Basin Storages

Storage	Current Annual Peak Flow Quantile						
	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	AVG.
Bow Lake	64 %	61 %	60 %	58 %	57 %	57 %	60 %
Tyee Regional R/D Pond	9 %	14 %	17 %	21 %	24 %	27 %	19 %
Northwest Ponds	29 %	29 %	28 %	27 %	26 %	25 %	27 %
Executel R/D Pond	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Marine View Drive Culvert	3 %	7 %	10 %	13 %	15 %	17 %	11 %

Industrial Waste System

It should be noted that predicted overflows of the lagoons for current conditions are hypothetical and may not match observed records. First and most obvious, the IWS treatment plant did not even exist before 1963 and the entire system has undergone several additions and modifications since that time. Less obvious, but still significant, are differences between actual and modeled treatment plant operations as they affect the rate of evacuation of the lagoons and discharge to the effluent outfall. Additionally, the model also assumes essentially unrestricted flow of IWS impervious area runoff to the plant which may not have actually occurred if the collection system backed up causing ponding and/or diversion of runoff to the storm drainage system. This ponding within the airport's drainage system are know to occur. In spite of these potential discrepancies, the model results still provide a useful estimate of expected overflow frequencies under the consistent application of the assumed IWS plant operations and contributing IWS drainage area.

The model predicted negligible overflow of the Industrial Waste System (IWS) over the entire simulation period. However, because of the lumped nature of the model's representation of the collection system and the lack of detailed hydraulics, confidence in this zero-overflow result is low. On the other hand, due to the storage-dominated character of the lagoon system, the model should be considered a good predictor of lagoon overflow. A summary of lagoon overflow events predicted by the model is given in Table A.9. No actual overflow occurred during the February 8, 1996, storm event.

Table A.9. Modeled Overflow of the IWS Lagoons

Overflow Date	Current Conditions Overflow Volume Amount ($Galx10^6$)	Current Conditions Treated Volume Amount ($Galx10^6$)	Future Conditions Overflow Volume Amount ($Galx10^6$)	Future Conditions Treated Volume Amount ($Galx10^6$)	Observed Condition
2/9/51	1.70	4.00	4.18	7.10	IWS not in existence
11/20/59	NONE	-	0.29	6.45	IWS not in existence
11/21/59	NONE	-	1.54	7.10	IWS not in existence
12/17/79	0.85	4.00	0.29	7.10	overflow occurred
12/18/79	0.46	3.16	0.20	7.10	no overflow occurred
1/9/90	NONE	-	0.55	6.45	no overflow occurred
4/5/91	NONE	-	1.49	6.74	no overflow occurred
2/8/96*	1.92	4.00	5.09	6.45	no overflow occurred

* No overflow was observed during the 2/8/96 storm event.

As shown in the table, under current conditions and operational assumptions as previously described, there are three events (combining the two days in December of 1979) with significant overflows over a period of 46 years for an average incidence of approximately one overflow event in 15 years. As might be expected, overflows tend to occur during extended periods of rainfall such as occurred in early February 1996 and also in 1951. Interestingly, the 26 percent projected future increase of IWS impervious area (254 acres to 320 acres) substantially increases the volume and frequency of predicted IWS lagoon overflows in spite of an assumed 73 percent increase in treatment rate (equivalent to lagoon evacuation rate). In the future, the frequency of possible overflow events doubles to one in seven and one-half (7.5) years and the average overflow volume increases by 38 percent.

Comparison of Peaks with Pre-Urbanized Pre-Development Conditions

A comparison of the current and pre-development condition flood frequency curves provides a useful measure of the hydrologic change that has occurred since the basin was cleared of forest and especially within the last 50 years which has witnessed construction of the airport and accelerated urbanization. As shown in Table A.10, flood peaks are currently two to twenty times greater than they were under pre-development conditions in spite of natural and constructed detention. More specifically, near the creek outlet, the discharge level that previously had been exceeded only once in 100 years on average is currently exceeded every two years. These large changes clearly demonstrate the effect of land use change within the basin, underscore the inadequacy of currently installed flood storage, and explain the increasing frequency with which older structures located near the creek have been damaged and flooded in recent decades.

Table A.10 Factors of Change Compared to Forested Condition for Des Moines Creek Basin

		2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
EB1	Bow Lake Inflow	10.8	6.5	5.2	4.3	3.9	3.6
EB2	Bow Lake Outflow	6.8	4.4	3.6	3.0	2.7	2.5
EB4	Tyee R/D Inflow	8.4	4.9	4.0	3.3	3.0	2.8
EB5	Tyee R/D Outflow	7.6	4.2	3.3	2.6	2.3	2.1
WB2	NW Ponds Inflow	21.4	12.9	10.2	8.1	7.0	6.3
WB3	NW Ponds Outflow	13.6	9.1	6.9	4.9	3.8	3.0
MS1	MS Above S. 200th St.	6.1	3.9	3.2	2.7	2.4	2.2
EX1	Executel R/D Inflow	8.5	5.6	4.8	4.1	3.8	3.6
EX2	Executel R/D Outflow	8.5	5.6	4.8	4.1	3.8	3.6
EX3	Executel Trib. Mouth	12.5	7.9	6.4	5.3	4.7	4.3
MS2	MS at Head of Ravine	7.6	4.8	3.9	3.3	3.0	2.7
MS3	MS Above N. Branch Ravine	7.5	4.8	4.0	3.4	3.4	2.9
NB1	N. Branch Ravine Mouth	8.8	6.0	5.1	4.6	4.3	4.2
MS4	MS at Inflow to MVD Box Culvert	7.1	4.5	3.8	3.3	3.0	2.9
MS5	MS Near Mouth	6.8	4.2	3.4	2.8	2.6	2.4

Channel Erosion and Flow Durations in Des Moines Creek Ravine

Channel erosion and related stream destabilization are complex and highly variable processes that depend, among other things, on the strength of bed and bank materials, the size of channel sediments and the time period over which stream flow forces significantly exceed critical levels. In the absence of a detailed understanding of these processes at each erosion site, a useful comparative index of stream erosivity and channel stability can be derived by summing the products of " excess effective flow" and the time periods over which these excess flows persist and subsequently normalizing by a comparable sum of products for a reference condition. Excess effective flows are all the positive arithmetic differences between instantaneous stream discharge and a critical discharge at which bed sediments first begin to move. Under quasi-stable stream conditions this critical discharge is taken as approximately the 1.5 year-recurrence interval peak flow or approximately 17 cfs at the head of the mainstem ravine under pristine, forested conditions. Under current conditions, critical discharge at this location has increased to approximately 40 cfs consistent with the enlargement of the channel cross section and coarsening of bed sediments that has occurred. A 40 cfs discharge occurs several times more frequently than once in 1.5 years on average- as would be expected for the current unstable channel condition in the ravine.

In figure A.10, current conditions are used as the normalizing reference value with a corresponding relative value of 1.0. By comparison, relative erosivity under forest conditions was less than one tenth the current value. This means that even when flows between 17 cfs and 40 cfs are discounted, current erosive flow durations are more than 10 times as persistent as under pristine, forested conditions.

Current Summer Base Flow Conditions

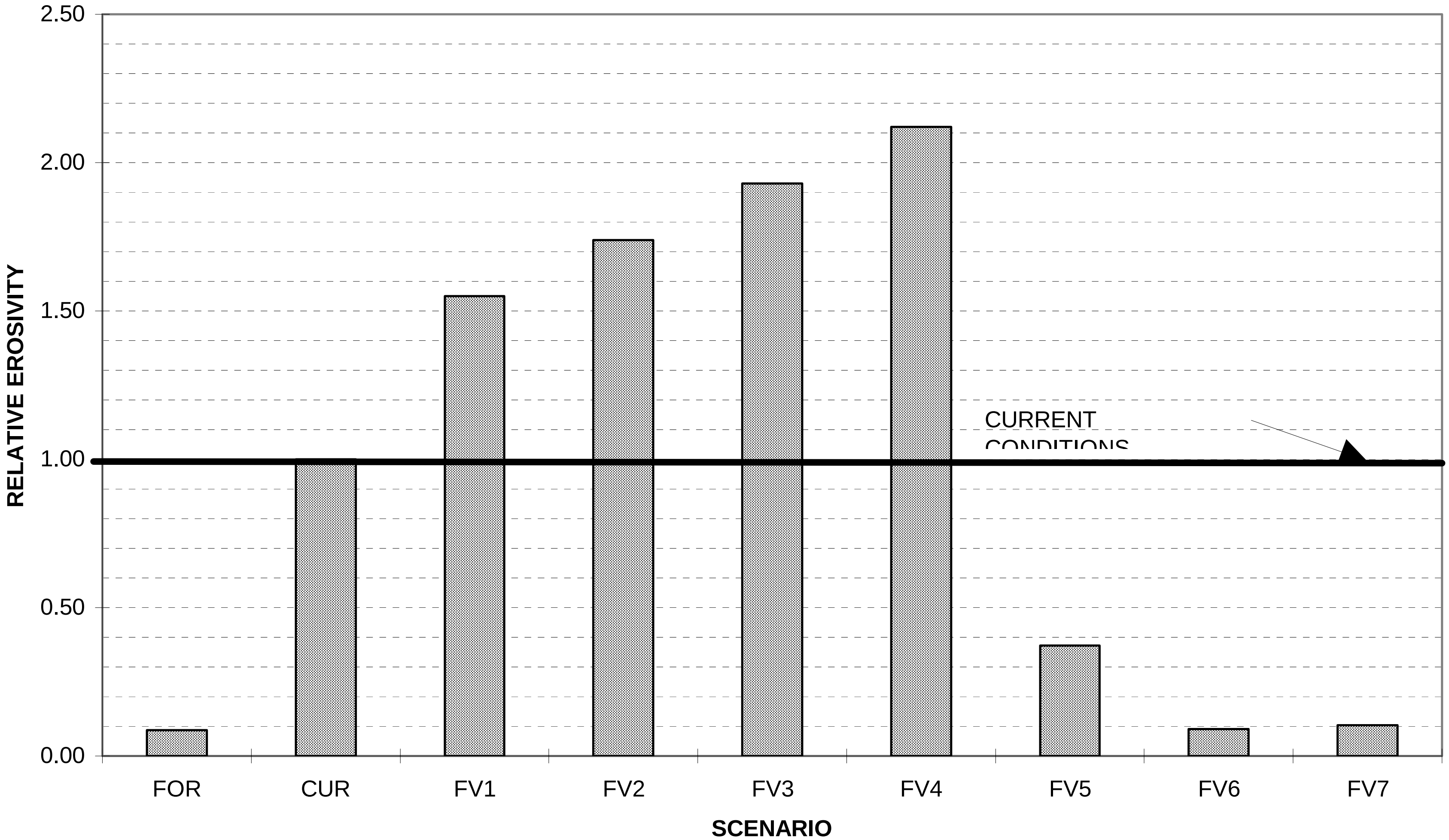
Base flow represents that portion of flow in a stream derived from groundwater discharge that persists for days and weeks following rainfall and declines very slowly over time. For purposes of comparison in this study, base flow is defined as the discharge that is exceeded 95 percent of time during the driest 6 months (April through September) of the year. On average, discharge falls below this level only 5 percent of the time during the driest part of the summer. It is therefore a good comparative measure of 'minimum' flow for fish habitat assessment, water quality and other purposes.

As shown in Table A.11, currently summer base flows in the mainstem of Des Moines Creek are 0.55 cfs and this represents approximately 21 percent loss since basin urbanization began. This result demonstrates that the currently elevated summer monthly mean discharges results from storm spikes while steady base flows have declined.

Table A.11 Effect of Urbanization on Base Flows

Scenario	Base Flow In Mainstem (Cfs)	Loss Relative To Forest
Forest	0.70	0 percent
Current	0.55	21 percent
Future (4, 5, & 6)	0.41	41 percent

Figure A.10 Stream Erosivity at MS-2



Projected Changes in Future Stream Flow Conditions

This section discusses estimated changes to annual peak flow, erosivity, and base flow in the Des Moines Creek system associated with the future land development and mitigation scenarios as summarized in the appendix. The potential for additional hydrologic change in the Des Moines Creek system is largely dependent on the amount and spatial distribution of new impervious surfaces associated with construction of homes, businesses, and larger infrastructure projects. Based on the future land use analysis that assumes full buildout to the limits of zoning, it would appear that the largest increment of future impervious surface derives from residential and commercial projects (future, scenario 1) that will be dispersed throughout the basin. Under future scenario 1, total basin impervious area increases by 439 acres from 1134 acres (30 percent) to 1573 acres (42 percent). In comparison, the 3rd runway, SASA, and Highway 509 projects add 67 (1.8 percent), 67 (1.8 percent), and 87 (2.3 percent) acres respectively to basin impervious area. A summary of catchment hydrologic cover composition (acreages of HRUs) and of increments of cover change associated with each scenario is given in Table A.12.

In addition to land cover change, future hydrologic conditions are also determined by drainage controls constructed by future development projects and by potentially new instream, regional flow control facilities.

Table A.12 Summary of Catchment Hydrologic Cover Composition and Cover Change by Scenario

DESCRIPTION	CATCH.	AREA (ACRES)	CURRENT - LAND COVER FOREST (ACRES)	GRASS (ACRES)	GROSS IMPERV. (ACRES)	IMPERV TO IWS	WETLAND (ACRES)
RESIDENTIAL UPSTREAM OF BOW LK.	1	427.4	19.0	244.4	148.7	0.0	2.7
HIGHWAY 99 CORRIDOR TO BOW LK.	2	59.6	2.2	10.6	45.4	0.0	1.3
COMMERCIAL TO BOW LK.	3	22.4	0.2	6.6	15.6	0.0	0.0
RES/COMM TO E. BRANCH	4	127.7	1.9	57.3	68.5	0.0	0.0
GOLF COURSE TO E. BRANCH	5	69.1	17.4	19.3	29.5	0.0	3.0
GOLF COURSE TO E. BRANCH	6	64.5	1.0	49.5	13.9	0.0	0.0
UPPER W. BRANCH	7	133.2	1.1	96.1	30.5	0.0	5.4
UPPER W. BRANCH	8	84.7	6.3	39.0	37.0	0.0	2.5
UPPER W. BRANCH	9	79.4	14.9	52.3	12.2	0.0	0.0
GOLF COURSE TO NW PONDS	10	44.5	25.7	14.1	2.4	0.0	1.2
GOLF COURSE TO NW PONDS	11	82.4	3.8	32.8	33.0	0.0	5.8
GOLF COURSE TO W. BRANCH	12	48.6	8.6	37.5	0.9	0.0	1.3
GOLF COURSE TO UPPER MAINSTEM	13	71.1	11.2	47.5	12.3	0.0	0.0
S. 200TH AREA TO UPPER MAINSTEM	14	53.6	31.2	19.2	3.1	0.0	0.0
S. 200TH AREA TO UPPER MAINSTEM	15	28.9	4.2	11.7	13.0	0.0	0.0
S. SEATAC TO EXECUTEL TRIB	16	278.6	17.4	149.4	109.8	0.0	2.0
S. SEATAC TO EXECUTEL TRIB	17	36.8	11.0	12.1	13.7	0.0	0.0
HEAD OF MAINSTEM RAVINE AREA	18	71.9	49.8	17.5	0.8	0.0	3.8
NORTH BRANCH RAVINE TRIB	19	180.4	4.3	139.0	37.1	0.0	0.0
S. SEATAC AND DES MOINES TO MIDDLE MAIN	20	353.3	106.1	175.4	70.1	0.0	1.8
DES MOINES TO LOWER MAINSTEM	21	275.0	52.0	152.9	70.1	0.0	0.0
DES MOINES TO LOWER MAINSTEM	22	132.8	7.6	93.3	31.6	0.0	0.2
AIRPORT, APPROX SDE-4 (NORTH TERMINAL)	23	227.4	1.3	41.1	185.1	37.1	0.0
AIRPORT, APPROX. SDS-1 (SOUTH TERMINAL)	24	127.9	0.0	13.1	114.8	74.9	0.0
AIRPORT, SDS-3 (RUNWAYS)	25	569.3	0.0	370.3	197.1	0.0	0.6
AIRPORT, SDW-3 (IWS VICINITY)	26	36.6	0.0	27.5	8.8	0.0	0.0
AIRPORT, SDS-4 (S. OF S. 188TH ST)	27	61.6	0.0	47.6	13.1	0.0	0.9
		3748.7	398.4	1977.0	1318.4	111.9	32.3
TOTAL CONTRIBUTING AREA		**3636.8**					

NOTES: MAJOR DIFFERENCES WITH MWG MODEL: 1. CATCHMENT 16 IS LARGER AND HAS MORE IMPERVIOUS

2. CATCHMENTS 19-22 REPRESENT LOWER BASIN THAT WAS NOT MODELED BY MWG

3. SMALL DIFFERENCES IN BASIN BOUNDARIES, ESPECIALLY CATCHMENT 23 AND 24 IN AIRPORT AREA. SUM OF AREAS FOR THESE IS SIMILAR IN BOTH MODELS HOWEVER.

Table A.12 continued

VERSION 2- LAND + 3RD RUNWAY					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	427.43	1.92	230.43	179.81	2.63
2	59.61	1.41	5.76	51.12	1.32
3	22.43	0.03	4.47	17.93	0.00
4	127.71	1.22	45.12	81.37	0.00
5	69.13	17.17	15.67	33.33	2.96
6	64.53	1.04	54.75	8.73	0.00
7	133.17	0.00	68.59	61.29	3.28
8	84.66	0.03	22.83	60.59	1.22
9	79.37	0.00	46.98	32.39	0.00
10	44.49	8.28	4.35	29.52	1.22
11	82.42	3.78	27.04	38.87	5.73
12	48.57	2.63	38.23	6.16	1.28
13	71.06	9.02	46.05	15.98	0.00
14	53.58	17.82	19.50	16.27	0.00
15	28.91	0.05	6.63	22.23	0.00
16	278.58	0.69	108.87	167.00	2.03
17	36.84	0.00	5.70	31.15	0.00
18	71.93	33.45	16.18	18.54	3.75
19	180.43	0.53	130.89	49.00	0.00
20	353.32	41.69	156.95	153.00	1.68
21	275.00	30.27	158.19	86.53	0.00
22	132.76	2.78	64.58	65.25	0.15
23	227.45	0.84	40.37	186.24	0.00
24	127.89	0.00	13.05	114.84	0.00
25	569.31	0.00	309.11	258.36	0.46
26	36.61	0.00	22.57	13.75	0.00
27	61.57	0.00	35.40	25.31	0.86
	3748.72	174.64	1698.25	1824.57	28.58

CHANGE DUE TO 3RD RUNWAY (FV1 TO FV2)					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	-0.01	0.01	0.00
6	0.00	0.00	0.98	-0.98	0.00
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	-2.97	3.48	-0.51
9	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.91	-0.91	0.00
13	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
23	0.00	-0.49	-0.55	1.04	0.00
24	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	-60.82	60.82	0.00
26	0.00	0.00	-3.98	3.98	0.00
27	0.00	0.00	0.00	0.00	0.00
		-0.49	-66.45	67.45	-0.51

Table A.12 continued

VERSION 3- LAND + 3RD RUNWAY + SASA					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	427.43	1.92	230.43	179.81	2.63
2	59.61	1.41	5.76	51.12	1.32
3	22.43	0.03	4.47	17.93	0.00
4	127.71	1.22	45.12	81.37	0.00
5	69.13	9.31	14.86	43.80	1.17
6	64.53	0.00	25.98	38.54	0.00
7	133.17	0.00	68.59	61.29	3.28
8	84.66	0.03	22.83	60.59	1.22
9	79.37	0.00	46.98	32.39	0.00
10	44.49	8.28	4.35	29.52	1.22
11	82.42	3.78	27.04	38.87	5.73
12	48.56	2.63	38.23	6.16	1.28
13	71.06	3.07	29.27	38.72	0.00
14	53.58	16.17	17.71	19.70	0.00
15	28.91	0.05	6.37	22.49	0.00
16	278.58	0.69	108.87	167.00	2.03
17	36.84	0.00	5.70	31.15	0.00
18	71.93	33.45	16.18	18.54	3.75
19	180.43	0.53	130.89	49.00	0.00
20	353.32	41.69	156.95	153.00	1.68
21	275.00	30.27	158.19	86.53	0.00
22	132.76	2.78	64.58	65.25	0.15
23	227.45	0.84	40.37	186.24	0.00
24	127.89	0.00	13.05	114.84	0.00
25	569.31	0.00	309.11	258.36	0.46
26	36.61	0.00	22.57	13.75	0.00
27	61.56	0.00	35.21	25.50	0.86
	3748.72	158.13	1649.64	1891.48	26.78

CHANGE DUE TO SASA (FV2 TO FV3)					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	-7.86	-0.81	10.47	-1.79
6	0.00	-1.04	-28.77	29.82	0.00
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00
13	0.00	-5.96	-16.78	22.74	0.00
14	0.00	-1.65	-1.79	3.44	0.00
15	0.00	0.00	-0.26	0.26	0.00
16	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	-0.19	0.19	0.00
		-16.51	-48.61	66.91	-1.79

Table A.12 continued

VERSION 4- LAND + 3RD RUNWAY + SASA + 509					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	427.4	1.9	230.4	179.8	2.6
2	59.6	1.4	5.8	51.1	1.3
3	22.4	0.0	4.5	17.9	0.0
4	127.7	1.2	45.1	81.4	0.0
5	69.1	7.5	14.4	46.1	1.2
6	64.5	0.0	17.7	46.8	0.0
7	133.2	0.0	68.6	61.3	3.3
8	84.7	0.0	22.8	60.6	1.2
9	79.4	0.0	47.0	32.4	0.0
10	44.5	8.3	4.4	29.6	1.1
11	82.4	3.8	27.0	38.9	5.7
12	48.6	2.6	37.3	7.1	1.3
13	71.1	2.4	25.9	42.7	0.0
14	53.6	0.5	13.2	39.9	0.0
15	28.9	0.1	6.4	22.5	0.0
16	278.6	0.1	98.4	179.4	0.7
17	36.8	0.0	5.7	31.2	0.0
18	71.9	5.5	13.4	53.0	0.0
19	180.4	0.5	130.9	49.0	0.0
20	353.3	41.7	154.7	156.8	0.2
21	275.0	30.3	158.2	86.5	0.0
22	132.8	2.8	64.6	65.2	0.2
23	227.4	0.8	39.8	186.8	0.0
24	127.9	0.0	13.1	114.8	0.0
25	569.3	0.0	309.1	258.4	0.5
26	36.6	0.0	22.6	13.7	0.0
27	61.6	0.0	35.2	25.5	0.9
	3748.69	111.47	1615.92	1978.58	20.07

CHANGE DUE TO HWY 509 (FV3 TO FV4)					
CATCH.	AREA (ACRES)	FOREST (ACRES)	GRASS (ACRES)	IMPERV. (ACRES)	WETLAND (ACRES)
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	-1.81	-0.48	2.29	0.00
6	0.00	0.00	-8.29	8.30	0.00
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.01	0.09	-0.10
11	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	-0.94	0.94	0.00
13	0.00	-0.63	-3.36	3.99	0.00
14	0.00	-15.70	-4.49	20.19	0.00
15	0.00	0.00	0.00	0.00	0.00
16	0.00	-0.60	-10.49	12.45	-1.35
17	0.00	0.00	-0.03	0.03	0.00
18	0.00	-27.92	-2.82	34.49	-3.75
19	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	-2.27	3.78	-1.51
21	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	-0.53	0.53	0.00
24	0.00	0.00	0.00	0.00	0.00
25	-0.03	0.00	-0.02	0.02	0.00
26	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00
		-46.66	-33.72	87.10	-6.72

Annual Flood Peaks

Flood frequency data for all scenarios are presented in Table A.13. These data indicate that only moderate increases (approximately 10-20 percent) in annual peak annual flow will occur depending on the level of buildout represented by future scenarios one through four. This demonstrates that 1990 KCSWDM standard detention ponds would be on average 80 - 90 percent successful in suppressing increases in flood peaks throughout the Des Moines Creek basin. Construction of larger stream protection detention ponds and a large regional storage facility in Tyee Valley Golf Course (Future Scenario 5) reduces current peaks by only 5 percent over the entire basin, and about 10 percent in the mainstem. In contrast, standard sized ponds and a smaller regional pond combined with a 42 cfs capacity bypass cuts flows in the ravine by more than 50 percent compared to current conditions. (Future Scenario 6). More importantly, this storage-bypass combination is also effective in reducing current levels of stream erosivity as discussed in the following section.

Future Stream Erosivity

The partial success of standard retention and detention ponds (Future Scenarios 1 through 4) in suppressing increases in peak annual discharge is not sustained for the problem of stream erosivity and channel instability. With each increment of development within the basin (as represented by Future Scenarios 1 through 4), the currently severe channel erosion problems may be expected to worsen. Only duration-control R/D ponds that are nearly three times larger than standard ponds are capable of restricting discharges below the erosive levels. Future Scenario 5 includes approximately 180 acre-feet assumed to be constructed by individual development projects and another 180 acre-feet of regional storage in Tyee Golf Course. The combination of these two storage areas is able to mitigate full basin buildout with all major projects to 40 percent of its current value and less than 20 percent of what it would be if only standard R/D ponds were constructed (Future Scenario 4). However, erosive energy would still be about four times greater than under stable conditions.

Similar to results for peak annual discharges Future Scenario 6, which combines a limited capacity high-flow bypass pipe with regional storage; results in significantly lower erosive conditions than scenario five. In terms of future basin wide storage, this scenario is a hybrid of Scenarios 4 and 5, combining 66 acre-feet of standard retention and detention ponds from individual projects with 180 acre-feet of new regional storage in the golf course. The key to the hydrologic performance of this scenario is the inclusion of the high-flow bypass pipe that drains the regional storage without impacting the mainstem channel. The bypass-regional storage combination mitigates future development and eliminates 80 percent of the increase in stream erosivity that has occurred as a result of basin urbanization to date. This scenario results in restoration of effective stream energy to pre-development, stable levels.

If a new, high-capacity (170 cfs) bypass were constructed (scenario seven), it is estimated that stream erosivity in the mainstem could also be fully restored to pre-developed levels. No new regional retention and detention storage would be required to achieve this level of restoration; however, a diversion structure would be required near South 200th Street to direct flow into the bypass line. Although the diversion and bypass would fully remediate the duration of peak discharges and hence the stream erosivity, channel erosion and transport; short-duration peaks would occasionally overcome the bypass capacity resulting in infrequent discharge spikes in the mainstem of the creek. This explains why peak annual flows are only partially restored to pre-developed levels while flow durations are 100 percent restored.

Future Summer Base Flow Conditions

Further construction of impervious surfaces are expected to reduce base flows by another 20 percent compared to forested conditions for a total loss of 41 percent under full buildout conditions (future scenarios 4, 5, and 6).

Table A.13 Flood Frequencies For Des Moines Creek Basin

CURRENT CONDITION		**2-YR (CFS)**	**5-YR (CFS)**	**10-YR (CFS)**	**25-YR (CFS)**	**50-YR (CFS)**	**100-YR (CFS)**
EB1	BOW LK. INFLOW	58	75	86	102	114	127
EB2	BOW LK. OUTFLOW	21	29	35	43	49	55
EB4	TYEE R/D INFLOW	73	93	108	127	142	158
EB5	TYEE R/D OUTFLOW	66	80	89	100	108	116
WB2	N.W. PONDS INFLOW	59	83	100	123	141	160
WB3	N.W. PONDS OUTFLOW	42	59	71	89	104	120
MS1	MS ABOVE S. 200 TH.	103	137	161	193	219	246
EX1	EXECUTEL R/D INFLOW	17	22	27	33	38	44
EX2	EXECUTEL R/D OUTFLOW	17	22	27	33	38	44
EX3	EXECUTEL TRIB MOUTH	32	41	48	56	63	70
MS2	MS AT HEAD OF RAVINE	127	169	198	237	268	301
MS3	MS ABOVE N. BRANCH RAVINE	149	199	235	282	320	360
NB1	NORTH BRANCH RAVINE MOUTH	15	21	25	32	38	44
MS4	MS AT INFLOW TO MVD BOX CULVERT	177	238	282	341	388	438
MS5	MS NEAR MOUTH	171	221	255	298	331	364

Table A.13 continued

FUTURE - SCENARIO 1		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	61	77	89	105	117	129
EB2	BOW LK. OUTFLOW	22	31	37	45	52	59
EB4	TYEE R/D INFLOW	74	95	109	128	143	159
EB5	TYEE R/D OUTFLOW	66	80	89	100	108	116
WB2	NW PONDS INFLOW	70	96	114	140	160	182
WB3	NW PONDS OUTFLOW	48	68	83	104	121	139
MS1	MS ABOVE S. 200 TH.	111	148	175	211	239	270
EX1	EXECUTEL R/D INFLOW	21	27	31	37	43	48
EX2	EXECUTEL R/D OUTFLOW	23	29	33	39	43	47
EX3	EXECUTEL TRIB MOUTH	34	42	48	56	62	68
MS2	MS AT HEAD OF RAVINE	142	188	222	269	306	347
MS3	MS ABOVE N. BRANCH RAVINE	166	220	260	316	361	409
NB1	NORTH BRANCH RAVINE MOUTH	14	19	23	28	33	38
MS4	MS AT INFLOW TO MVD BOX CULVERT	202	268	317	385	440	498
MS5	MS NEAR MOUTH	189	241	276	321	354	389

FUTURE - SCENARIO 2		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	61	77	89	105	117	129
EB2	BOW LK. OUTFLOW	22	31	37	45	52	59
EB4	TYEE R/D INFLOW	74	95	109	128	143	159
EB5	TYEE R/D OUTFLOW	66	80	89	100	108	116
WB2	NW PONDS INFLOW	76	102	120	146	167	189
WB3	NW PONDS OUTFLOW	54	75	90	111	128	146
MS1	MS ABOVE S. 200 TH.	116	153	180	217	246	277
EX1	EXECUTEL R/D INFLOW	21	27	31	37	43	48
EX2	EXECUTEL R/D OUTFLOW	23	29	33	39	43	47
EX3	EXECUTEL TRIB MOUTH	34	42	48	56	62	68
MS2	MS AT HEAD OF RAVINE	151	199	234	282	320	361
MS3	MS ABOVE N. BRANCH RAVINE	169	225	265	322	368	417
NB1	NORTH BRANCH RAVINE MOUTH	14	19	23	28	33	38
MS4	MS AT INFLOW TO MVD BOX CULVERT	205	273	323	391	447	506
MS5	MS NEAR MOUTH	193	245	279	324	357	391

Table A.13 continued

FUTURE - SCENARIO 3		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	61	77	89	105	117	129
EB2	BOW LK. OUTFLOW	22	31	37	45	52	59
EB4	TYEE R/D INFLOW	77	98	113	132	148	164
EB5	TYEE R/D OUTFLOW	68	82	91	102	109	117
WB2	NW PONDS INFLOW	76	102	120	146	167	189
WB3	NW PONDS OUTFLOW	54	75	90	111	128	146
MS1	MS ABOVE S. 200 TH.	118	155	182	219	248	278
EX1	EXECUTEL R/D INFLOW	21	27	31	37	43	48
EX2	EXECUTEL R/D OUTFLOW	23	29	33	39	43	47
EX3	EXECUTEL TRIB MOUTH	34	42	48	56	62	68
MS2	MS AT HEAD OF RAVINE	155	204	239	287	326	367
MS3	MS ABOVE N. BRANCH RAVINE	173	229	270	327	373	423
NB1	NORTH BRANCH RAVINE MOUTH	14	19	23	28	33	38
MS4	MS AT INFLOW TO MVD BOX CULVERT	209	277	327	396	452	512
MS5	MS NEAR MOUTH	196	248	282	326	359	393

FUTURE - SCENARIO 4		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	61	77	89	105	117	129
EB2	BOW LK. OUTFLOW	22	31	37	45	52	59
EB4	TYEE R/D INFLOW	78	100	115	135	151	168
EB5	TYEE R/D OUTFLOW	69	83	92	103	111	119
WB2	NW PONDS INFLOW	76	102	120	146	167	189
WB3	NW PONDS OUTFLOW	54	75	90	111	128	146
MS1	MS ABOVE S. 200 TH.	118	156	184	220	250	281
EX1	EXECUTEL R/D INFLOW	22	28	32	39	44	50
EX2	EXECUTEL R/D OUTFLOW	24	30	34	40	44	48
EX3	EXECUTEL TRIB MOUTH	35	43	49	57	63	69
MS2	MS AT HEAD OF RAVINE	160	210	247	298	339	383
MS3	MS ABOVE N. BRANCH RAVINE	177	235	279	340	391	446
NB1	NORTH BRANCH RAVINE MOUTH	14	19	23	28	33	38
MS4	MS AT INFLOW TO MVD BOX CULVERT	213	283	335	408	467	531
MS5	MS NEAR MOUTH	200	252	287	332	367	401

Table A.13 continued

FUTURE - SCENARIO 5		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	60	76	88	103	115	128
EB2	BOW LK. OUTFLOW	14	24	31	42	51	61
EB4	TYEE R/D INFLOW	68	87	102	121	136	153
EB5	TYEE R/D CONNECTED TO REG. POND	-	-	-	-	-	-
WB2	NW PONDS INFLOW	69	93	110	133	151	170
WB3	REPLACED BY REGIONAL POND	-	-	-	-	-	-
MS1	MS ABOVE S. 200 TH.	60	110	149	205	251	301
EX1	EXECUTEL R/D INFLOW	19	24	28	33	38	42
EX2	EXECUTEL R/D OUTFLOW	22	27	31	36	39	43
EX3	EXECUTEL TRIB MOUTH	32	39	44	51	56	62
MS2	MS AT HEAD OF RAVINE	72	122	166	235	298	372
MS3	MS ABOVE N. BRANCH RAVINE	84	137	183	257	326	409
NB1	NORTH BRANCH RAVINE MOUTH	13	18	22	28	32	37
MS4	MS AT INFLOW TO MVD BOX CULVERT	119	178	228	306	375	456
MS5	MS NEAR MOUTH	117	167	208	270	324	385

FUTURE - SCENARIO 6		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	61	77	89	104	117	129
EB2	BOW LK. OUTFLOW	15	25	33	44	53	63
EB4	TYEE R/D INFLOW	72	93	109	130	147	165
EB5	TYEE R/D OUTFLOW	PIPED TO NORTHWEST PONDS					
WB2	N.W. PONDS INFLOW	76	102	121	147	168	190
WB3	N.W. PONDS OUTFLOW	9	16	27	53	90	154
MS1	MS ABOVE S. 200 TH.	25	36	50	77	108	152
EX1	EXECUTEL R/D INFLOW	22	28	32	39	44	49
EX2	EXECUTEL R/D OUTFLOW	27	33	38	43	48	52
EX3	EXECUTEL TRIB MOUTH	39	48	54	62	69	75
MS2	MS AT HEAD OF RAVINE	68	91	112	145	176	211
MS3	MS ABOVE N. BRANCH RAVINE	89	120	146	185	220	260
NB1	NORTH BRANCH RAVINE MOUTH	16	22	26	33	39	45
MS4	MS AT INFLOW TO MVD BOX CULVERT	128	171	205	254	296	343
MS5	MS NEAR MOUTH	127	164	192	232	266	302

FUTURE - SCENARIO 7		2-YR (CFS)	5-YR (CFS)	10-YR (CFS)	25-YR (CFS)	50-YR (CFS)	100-YR (CFS)
EB1	BOW LK. INFLOW	62	79	91	107	119	132
EB2	BOW LK. OUTFLOW	16	27	35	48	58	70
EB4	TYEE R/D INFLOW	73	95	112	135	153	173
EB5	TYEE R/D OUTFLOW	PIPED TO NORTHWEST PONDS					
WB2	N.W. PONDS INFLOW	77	104	124	151	173	197
WB3	N.W. PONDS OUTFLOW	15	31	46	73	101	135
MS1	MS ABOVE S. 200 TH.	30	49	65	93	118	149
EX1	EXECUTEL R/D INFLOW	22	28	33	40	45	51
EX2	EXECUTEL R/D OUTFLOW	28	34	38	44	49	54
EX3	EXECUTEL TRIB MOUTH	39	49	55	63	69	76
MS2	MS AT HEAD OF RAVINE	72	101	125	162	194	231
MS3	MS ABOVE N. BRANCH RAVINE	93	130	160	205	245	290
NB1	NORTH BRANCH RAVINE MOUTH	16	22	27	34	40	46
MS4	MS AT INFLOW TO MVD BOX CULVERT	130	179	218	275	323	378
MS5	MS NEAR MOUTH	130	171	203	247	284	325

APPENDIX B - WATER QUALITY

Instream Water Quality

The water quality of Des Moines Creek reflects that expected of an urban watershed. Fecal coliform bacteria are a human health concern in both storm and baseflows. High water temperatures likely produce chronic stresses on aquatic biota during the late summer. Dissolved oxygen concentrations in the mainstem appear to be adequate. During storms, suspended solids and turbidity, ammonia, and toxic metals reach levels which may acutely stress aquatic life in the stream.

The following discussion is broken into discussions of stormwater and baseflow quality with a separate discussion of fecal coliform source tracing. These analyses are compiled from monitoring programs undertaken by several jurisdictions within the Des Moines Creek watershed, listed in Table B.1.

Table B.1 Water Quality Monitoring for Des Moines Creek

Jurisdiction	Dates	Type of Sampling (Storm and/or Baseflow)
City of Des Moines Water Quality Program	1995-1996	Storm, Baseflow
Port of Seattle	1996	Storm
Herrera Environmental Consultants	1994-1995	Storm, Baseflow
King County Surface Water Management Division	1996	Storm, Baseflow

Fecal Coliform Source Tracing

Fecal coliform counts during both storm and baseflows exceeded Washington State Class AA Standards (see Stormwater Quality and Baseflow Water Quality sections below), reaching levels high enough to be a human health concern. Based on this information, King County Surface Water Management (SWM) initiated a fecal coliform source tracing effort, using ribosomal RNA typing to identify the source of the fecal contamination. All samples collected by SWM exceeded the Class AA Standard of 50 CFU/100mL. The RNA procedure, which matches the RNA of the sampled coliforms with those from known sources, implicated human sources as a major contributor to fecal contamination in Des Moines Creek.

Samples were collected at four sites (Figure B.1). One set of stormwater samples was collected December 2, 1996. Two more sets of samples were collected on December 24, 1996, with an approximate one half hour interval between samples. Counts from these samples are presented in Figure B.1.

The RNA results are also presented in Figure B.1. The RNA analysis left a substantial number of RNA isolates unmatched, meaning that the RNA strains in the samples did not correspond to any pattern in the database of known strains. Despite the number of unmatched strains, the data strongly imply a higher human proportion of fecal strains downstream of the high density residential unsewered areas. For the samples collected at mainstem site DMFC2, 64 percent of the strains matched human/septic sources and only 36 percent were unmatched. Sampling site

DMFC3, on the small right bank tributary near stream mile 0.9, was also downstream of a largely unsewered area; there more unmatched strains (57 percent) at this site, but human/septage strains (31 percent) dominated the matched strains. In headwater areas (DMFC4 and DMFC5), 50 percent or more of the strains remained unmatched, and for the matched strains, avian and canine sources equaled or exceeded human sources.

Microbiology specialists at the King County Environmental Laboratory caution that the above results are limited by two factors: (1) the small number of samples, and (2) the number of ribosomal patterns in the database of known sources. The number of samples is considered adequate when no new patterns emerge, and the patterns start repeating. This did not occur in the limited sample set. The RNA database, housed at the University of Washington, has substantially more ribosomal patterns isolated from animal sources than from human and septage sources. Further inclusion in the database of ribosomal patterns from known sources in the region – specifically human, septage, and animal sources in the Des Moines Creek Basin – would very likely result in more matches.

Stormwater Quality

Table B.2 summarizes the stormwater data collected as part of the City of Des Moines Water Quality Monitoring program from 1994 to 1996. Table B.3 presents the 1995 storm sampled by the Port of Seattle. The results of both efforts are similar, indicating increases in total suspended solids, fecal coliforms, nitrate+nitrite and total phosphorus from upstream (DM1) to downstream (DM2- mouth of creek).

Table B.2 City of Des Moines Stormwater Quality Results Summary

		MEANS			
		Upstream (DM 1)[1]		**Downstream (DM 2)[1]**	
Parameter	**Units**	**1994-1995[2]**	**1995-1996**	**1994-1995[2]**	**1995-1996**
Turbidity	NTU	21	17	17	20
Conductivity	umhos/cm	110	87	116	106
Total Suspended Solids	mg/l	46	51	70	88
Total Petroleum Hydrocarbons	mg/l	0.25	0.42	0.25	0.31
Fecal Coliforms	#/100ml	838	411	1612	3864
Total Phosphorous	μ/l	169	170	233	216
Ammonia	μ/l	205	70	156	42
Nitrate + Nitrite	μ/l	653	460	848	647
Hardness	μ/l	46.6	35.9	59.7	44.0
Dissolved Copper	μ/l	7.5	8.6	4.8	6.5
Dissolved Lead	μ/l	0.9	0.7	0.8	0.6
Dissolved Zinc	μ/l	42	21	29	132
Total Copper	μ/l	25.2	22.3	27.5	128
Total Lead	μ/l	15.4	10.9	13.3	117
Total Zinc	μ/l	104	487	63	42

1 Collected for the City of Des Moines Water Quality Program
DM 1 is located at South 200th Street
DM 2 is located at the mouth of Des Moines Creek
2 Hererra, 1995

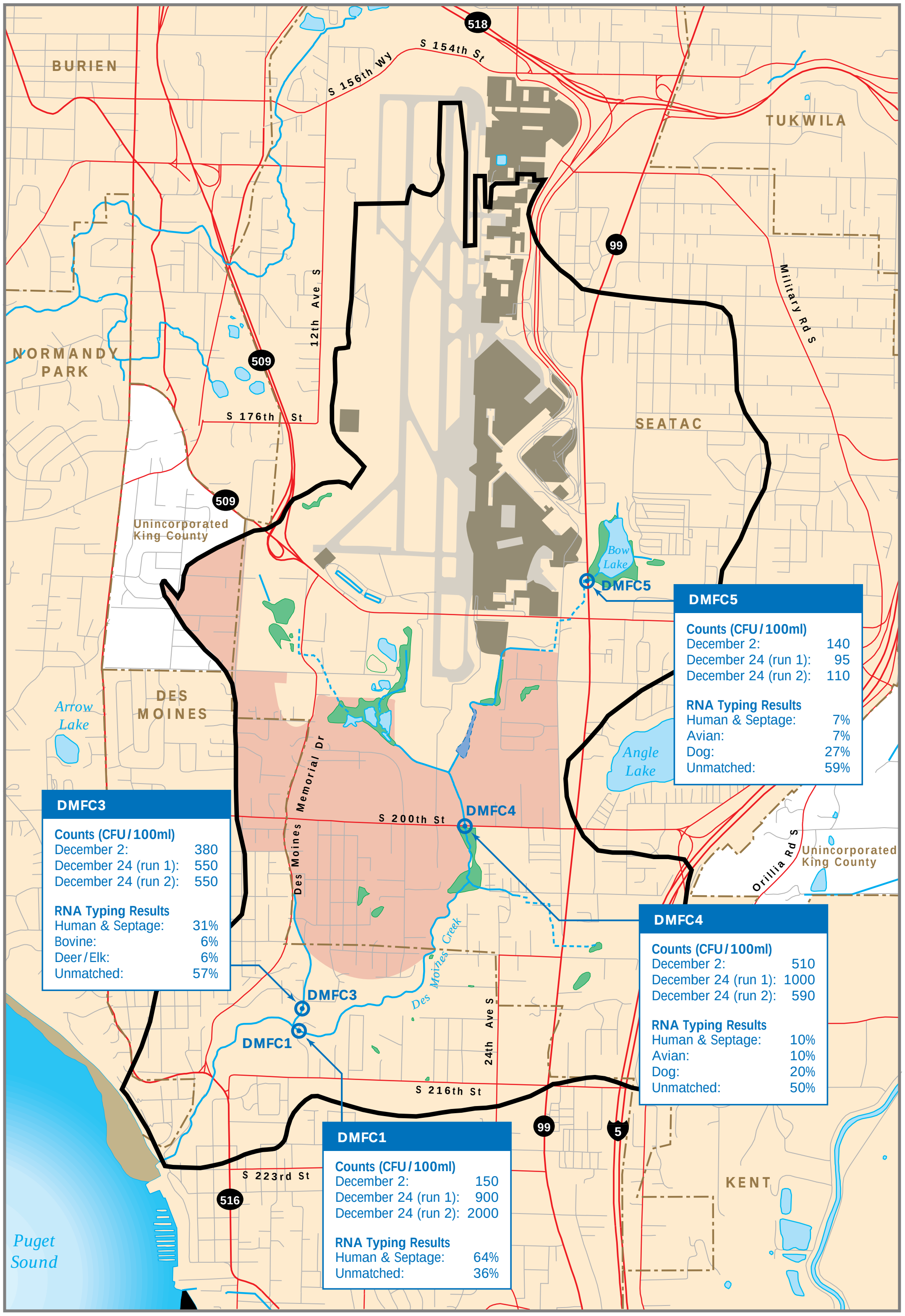


Figure B-1

DES MOINES CREEK BASIN

Fecal Coliform RNA Source Tracing Results: December 1996

N

0 — 1/2 Mile

October 1997

DMFC1 Sampling Site & Number
Approximate Unsewered Area
Basin Boundary
Stream
Piped Stream
Incorporated Area
Industrial Wastewater System
Lake
Wetland
R/D Facility

Map produced by: King County DNR GIS/Cartography/Graphics Unit

Sewered Area Sources:
City of SeaTac Comprehensive Plan, 1994
King County, Planning and Community Development GIS Database

9710DMfecalB-1.pdf WG

Table B.3 Port of Seattle Stormwater Quality Results Des Moines Creek Storm May 23, 1996.

	S. 28th	Above Weir #1	Upstream of NW Ponds Inlet	Discharge Culvert at NW Ponds Outlet	Mouth of Creek (DM 2)
pH	No Data	7.5	7.5	7.4	7.8
Total Suspended Solids	10	9	6	3	17
Total Phosphorous	0.0690	0.0630	0.0510	0.0660	0.071
BOD	22	31	22	5	5
Total Petroleum Hydrocarbons	1	<1	<1	<1	<1
Total Recoverable Cadmium	0.0003	0.0001	<0.0002	<0.0002	0.0008
Total Recoverable Copper	0.0128	0.0121	0.0056	0.0005	0.0453
Total Recoverable Lead	0.0072	0.0046	0.0020	0.0007	0.0182
Total Recoverable Nickel	0.0021	0.0025	0.0019	0.0023	0.0041
Total Recoverable Silver	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Total Recoverable Zinc	0.0665	0.0288	0.0269	0.0063	0.2427
Dissolved Cadmium	0.0002	<0.0002	<0.0002	<0.0002	0.0006
Dissolved Copper	0.0106	0.0097	0.0051	0.0005	0.0343
Dissolved Lead	0.0015	0.0010	0.0023	<0.0005	0.0032
Dissolved Nickel	0.0018	0.0022	0.0018	0.0026	0.0035
Dissolved Silver	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Dissolved Zinc	0.0515	0.0197	0.0223	0.0058	0.1750
Hardness	26	52	60	80	68
Dissolved Oxygen & Temperature[1]					
Sample 1	No Data	7.6(13.4)	9.8(11.4)	5.4(14.7)	9.9(11.5)
Sample 2	No Data	7.6(13.8)	9.3(12.2)	6.5(14.7)	9.9(11.9)
Sample 3	No Data	9.7(12)			10(14.0)

[1] Dissolved Oxygen values taken periodically and randomly during the storm over an approximated 16-hour period; numbers outside parentheses is the Dissolved Oxygen value and number inside parentheses is water temperature.

Table B.4 presents typical instream ranges and thresholds corresponding to some of these pollutants. The local data are from stormwater runoff collected from developed areas and developments in King and Snohomish Counties (King County, 1993b). The typical ranges are from the National Urban Runoff Program (NURP), representing an accepted general characterization of urban runoff-pooled data from many urban sites and developed land uses except for open land. Washington state criteria do not exist for total suspended solids, total phosphorus, and nitrate-nitrite; however, these thresholds were developed from literature or recommended by the U.S. Environmental Protection Agency (EPA). It should be noted that these thresholds were developed for baseflow conditions (average conditions over long periods of time) and therefore do not directly relate to stormwater events (intermittent, intense conditions) but do provide a guideline beyond which the health of aquatic species may be compromised. The Washington state water quality standards were also developed for baseflow conditions.

Table B.4 Typical Urban In-Stream Wet Weather Concentrations and Recommended Threshold Values for Surface Water Quality

	King and Snohomish Data			NURP [2]	
Parameter	**Low Range [1]**	**Moderate Range [2]**	**High Range [1]**	**National Averages [2]**	**Threshold**
TSS (mg/l)	5-30	30-100	100-1500	141-244	50 mg/l [3]
TP (mg/l)	0.02-0.1	0.10-0.5	0.5->5	0.3-0.5	0.1 mg/l [3]
NO2+NO3	0.10-0.30	0.30-0.50	0.50-1.0	0.76-0.96	1.25 mg/l [4]
Zn (mg/l)	0.05-0.10	0.10-0.25	0.25-1.0	--	0.065/0.059 mg/l [5]
TPH (mg/l)	0.4-<2	2-6	10->30	--	none established

(1) King County, 1993b
(2) EPA, 1983
(3) King County, 1993c
(4) King County, 1990d
(5) WAC 173-201 based on 50 mg/l CaCO3 Hardness : acute/chronic

Stormwater quality concentrations of total suspended solids and phosphorus exceed the thresholds presented in Table B.4. Fecal coliform concentrations greatly exceed the Class AA standard of 50/100ml.

Table B.5 shows the acute and chronic metal criteria for Des Moines Creek based on an assumed hardness of 50mg/l $CaCO_3$. Chronic levels will stress aquatic life affecting overall health, reproductivity, and endurance. Acute levels represent concentrations that have the potential to be directly and immediately lethal to aquatic life. The WSDOE has established criteria for metals -- chronic limit is four day average concentration not to be exceeded more than once every three years. The acute limit is a one hour average concentration not to be exceeded more than once every three years.

Table B.5. Washington State AA Acute and Chronic Metals Standards*.

	Acute	Chronic
Arsenic, total	360	190
Cadmium, dissolved	1.6	0.57
Chromium (VI)	16	11
Chromium (III) (or total)	984	34
Copper, dissolved	8.0	1.5
Lead, dissolved	23	0.13
Mercury, total	2.4	0.012
Nickel, dissolved	750	23
Silver, dissolved	0.65	---
Zinc, dissolved	58	15

*Based on an assumed hardness of 50 mg/L $CaCO_3$

Stormwater sample concentrations of zinc and some copper samples exceeded the chronic and acute concentrations; however, due to the grab sampling method, the duration of exceedance is not known. Baseflow concentrations are below the standards. This indicates that during storm events, for some undetermined amount of time, copper and zinc concentrations exceed levels recommended for the protection of aquatic life and could stress aquatic life depending on the duration of the exceedance. However, no fish kills have been observed after storm events and the severity of exceedances at this time is not of great concern.

Baseflow Water Quality

Table B.6 presents the baseflow water quality results for 1994 through 1996. All the parameters are below the thresholds presented in Table 3.2 and are fairly typical of urban stream baseflow concentrations. The fecal coliform concentrations are of concern, exceeding the Class AA standard of 50/100 ml and present a human health risk. On average, the range of concentrations of baseflow pollutants are similar upstream to downstream.

Table B.6 Comparison of Baseflow Water Quality Results

		Station DM-1 (Upstream)		
Parameter	**Units**	**12/7/95**[1]	**3/27/96**[1]	**1994-1995 Mean**[2]
Turbidity	NTU	2.8	1.6	2.1
Total Suspended Solids	mg/l	1.5	1.8	1.2
Fecal Coliforms	#/100ml	500	est. 26	91
Total Phosphorus	mg/l	0.036	0.040	0.050
Ammonia	mg/l	0.058	0.024	0.026
Nitrate + Nitrite	mg/l	0.923	0.685	0.830
Hardness	mg/l	72.9	87.5	81.5
Dissolved Copper	μg/l	0.0037	0.0016	0.0026
Dissolved Lead	μg/l	0.0005	<0.0005	0.0005
Dissolved Zinc	μg/l	0.005	0.009	0.007

Table B.6 continued

Station DM-2 (Downstream)

Parameter	**Units**	**12/7/95[1]**	**3/27/96[1]**	**1994-1995 Mean[2]**
Turbidity	NTU	2.1	1.7	2.1
Total Suspended Solids	mg/l	1.2	1.5	3.7
Fecal Coliforms	#/100ml	400	est. 30	332
Total Phosphorus	mg/l	0.038	0.028	0.048
Ammonia	mg/l	0.079	0.018	0.020
Nitrate + Nitrite	mg/l	0.974	0.919	0.790
Hardness	mg/l	80.2	89.0	88.5
Dissolved Copper	µg/l	0.0033	0.0019	0.0017
Dissolved Lead	µg/l	<0.0005	<0.0005	0.0007
Dissolved Zinc	µg/l	0.005	0.003	0.006

[1] Collected for the Des Moines Creek Water Quality Program, City of Des Moines
[2] Hererra, 1995
NOTE: DM-1 is located at S. 200th Street
DM-2 is located at the mouth of Des Moines Creek

Figures B.2 through B.5 present the results of four continuous baseflow water quality monitoring periods in 1996; these monitoring periods also inadvertently included several storms. Water temperatures reached levels well above the range for salmonids, but did not exceed lethal limits. Dissolved oxygen concentrations appeared adequate to support a full range of aquatic biota. Turbidity levels during high flows are a concern because of the deleterious effects of fine sediment deposition following storms. Water quality at the upstream (S. 200th St.) and downstream (WWTP) monitoring stations was very similar, although generally slightly better at the downstream location.

Temperature

Water temperatures in the mainstem of Des Moines Creek exceeded the optimal temperature for rearing salmonids present in Des Moines Creek (14°C) for sustained periods from April through September 1996, reaching as high as 20.5°C. Temperatures throughout the summer were in the range of chronic stress for salmonids. Temperatures also regularly exceeded the Washington State standard of 16°C during this period. Although maximum temperatures did not exceed lethal limits for salmonids, they were near that margin (around 22°C); any further increases in maximum water temperatures could have a much greater incremental impact on fish populations in Des Moines Creek. Water temperatures recorded from January 1 to September 6, 1996 at S. 200th Street and the WWTP are graphed in Figure B.2.

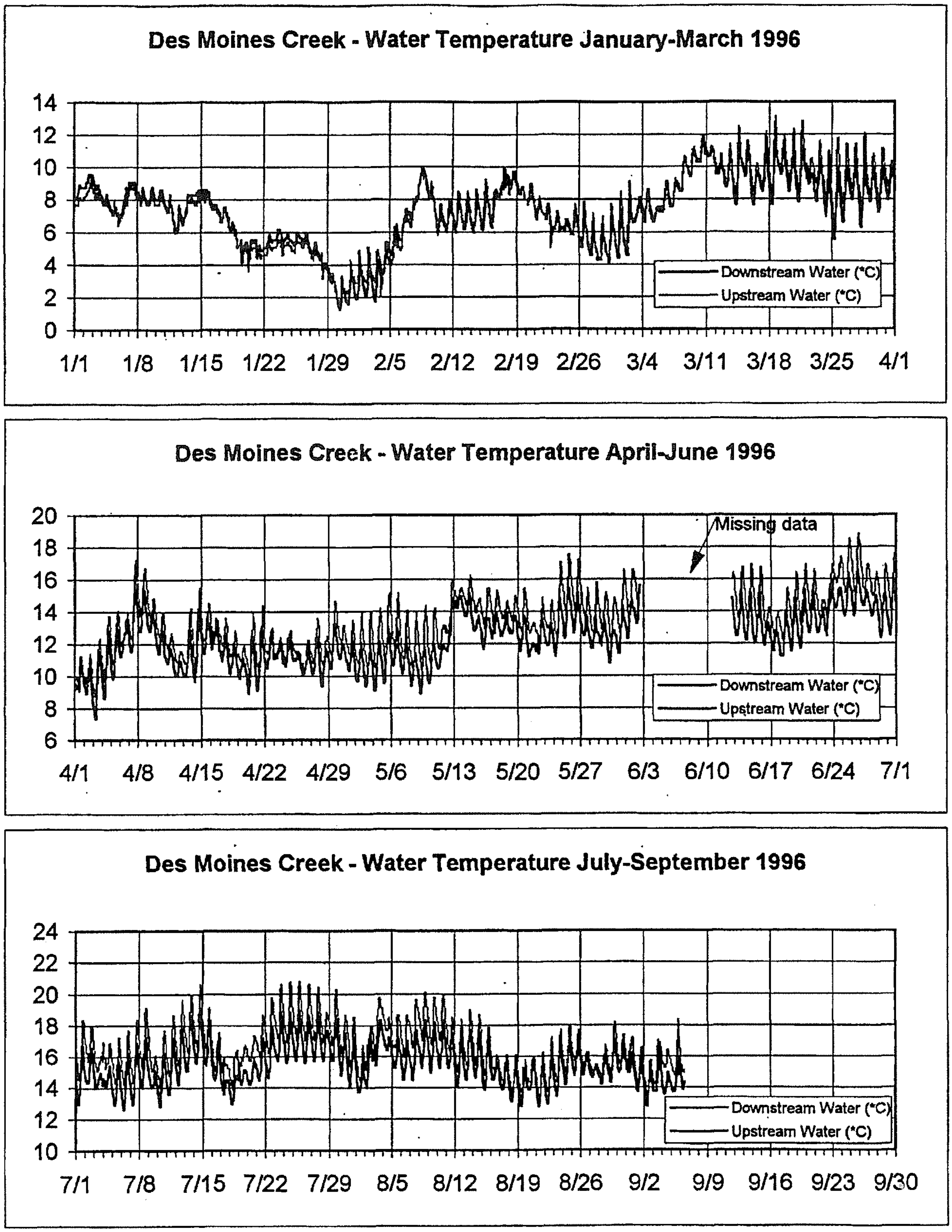
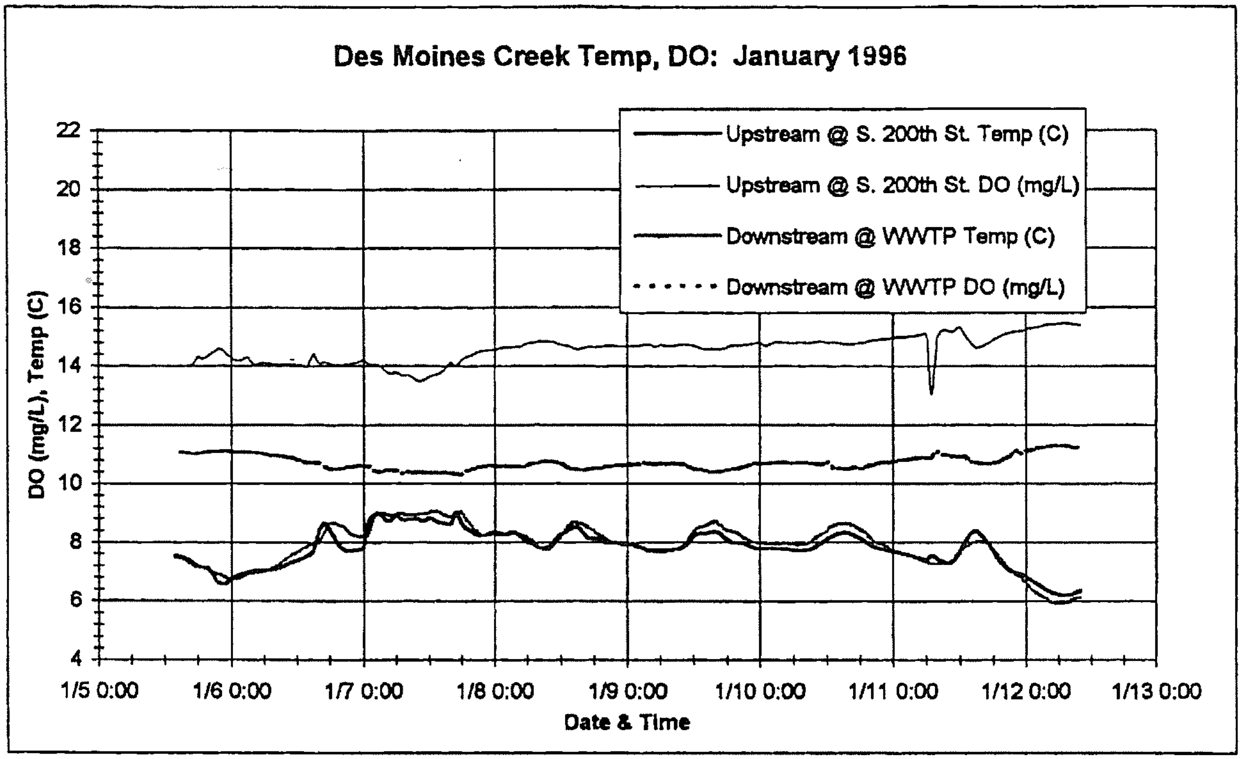


Figure B.2. Des Moines Creek water temperature at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.



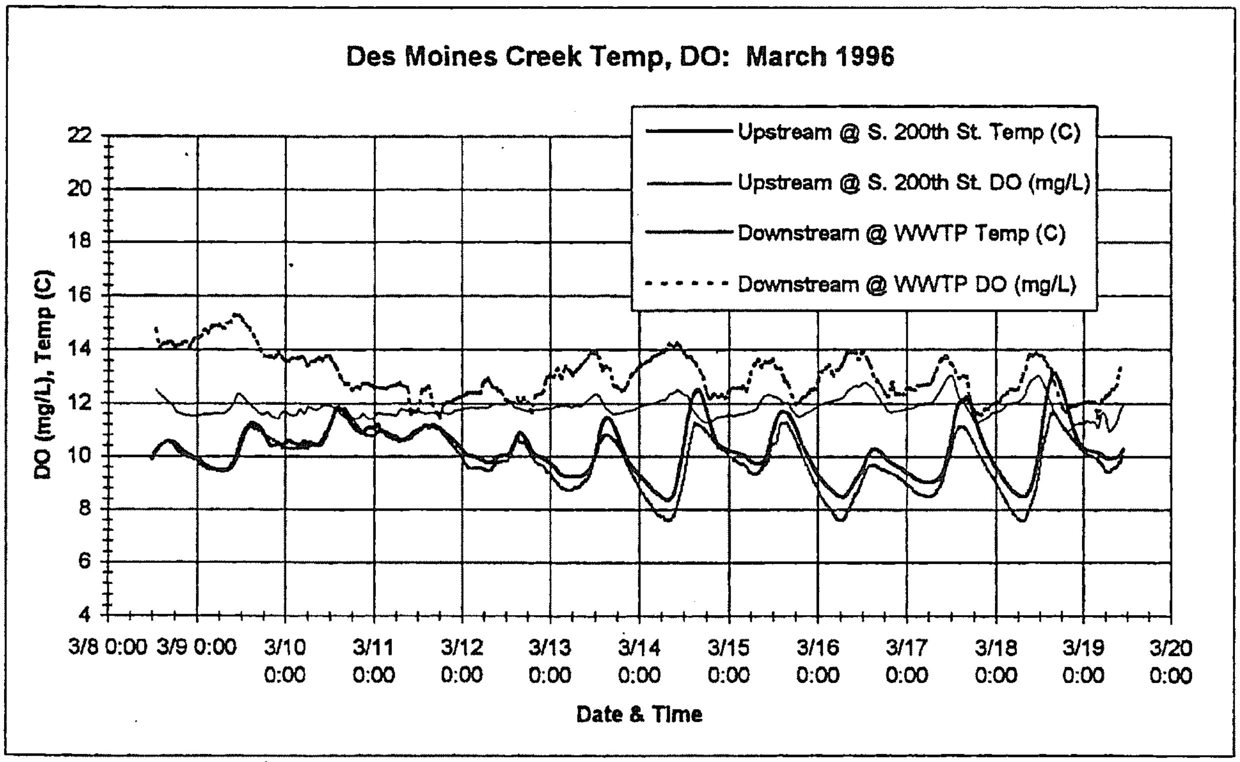
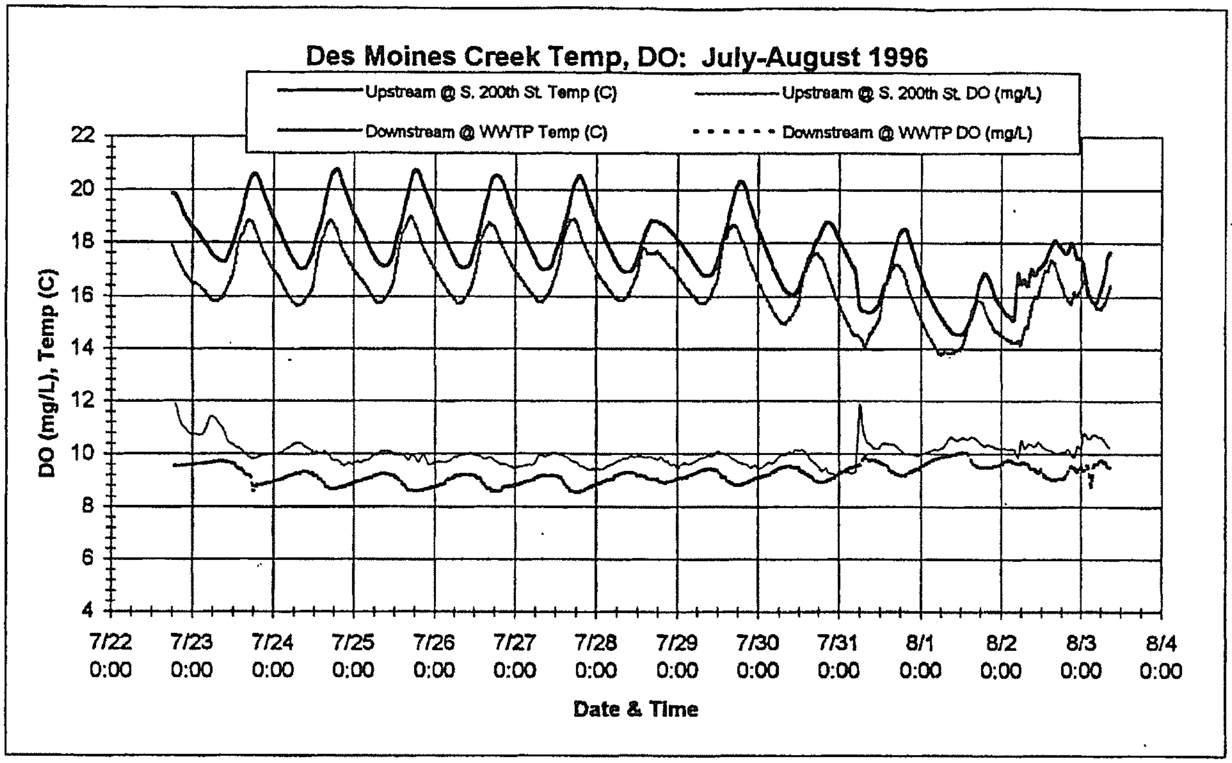


Figure B.3. Des Moines Creek dissolved oxygen at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.



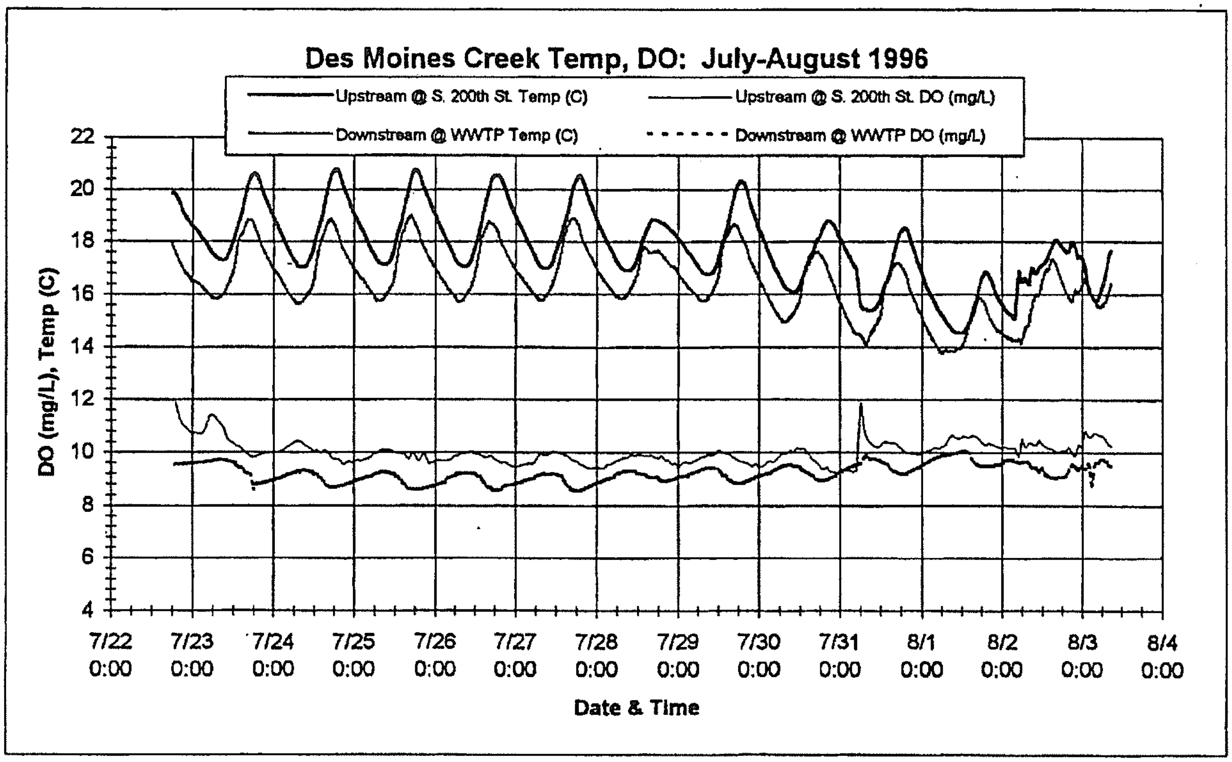


Figure B.3 (continued). Des Moines Creek dissolved oxygen at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.

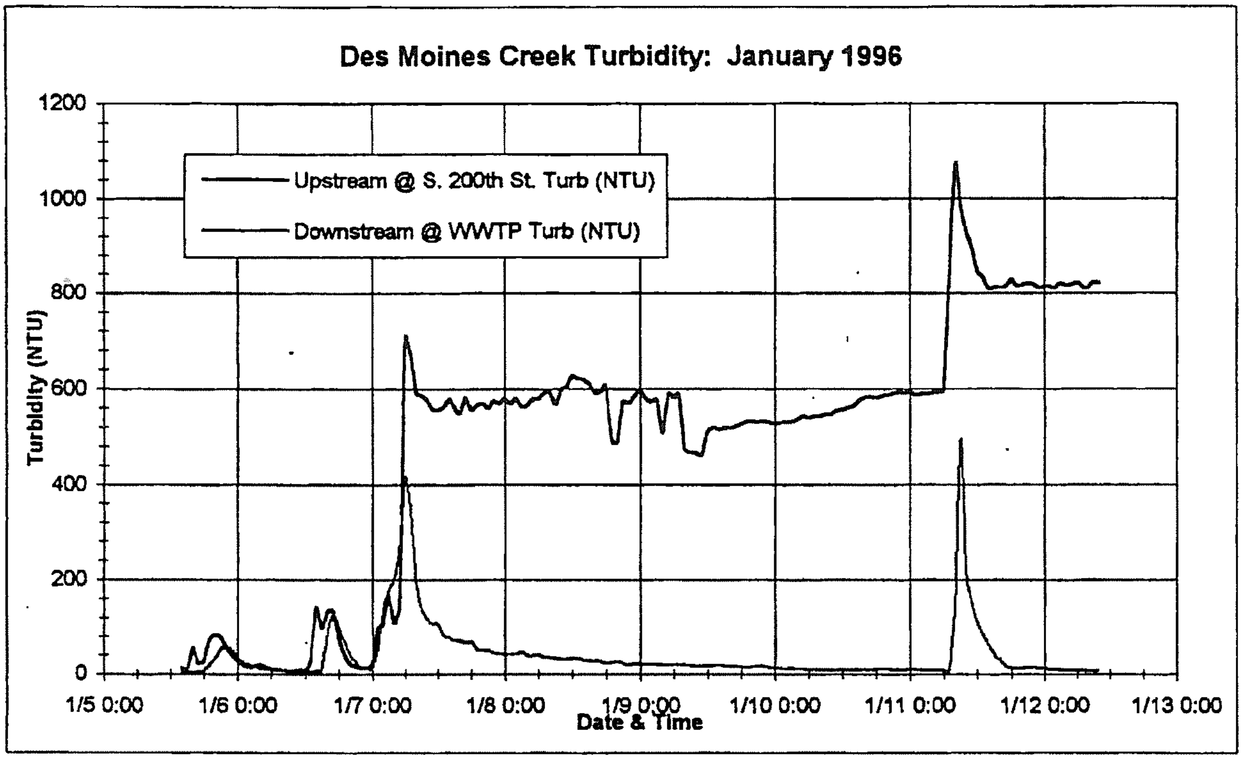
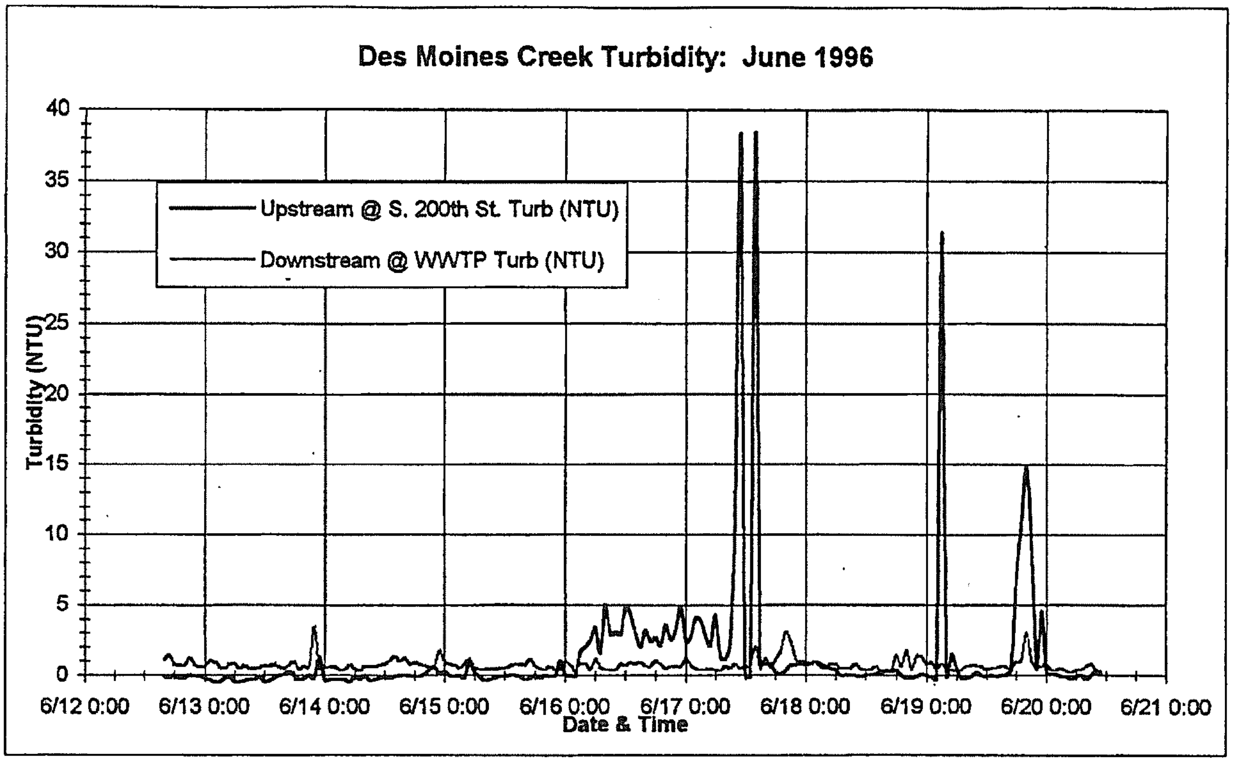


Figure B.4. Des Moines Creek turbidity at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations. No turbidity data available for March.



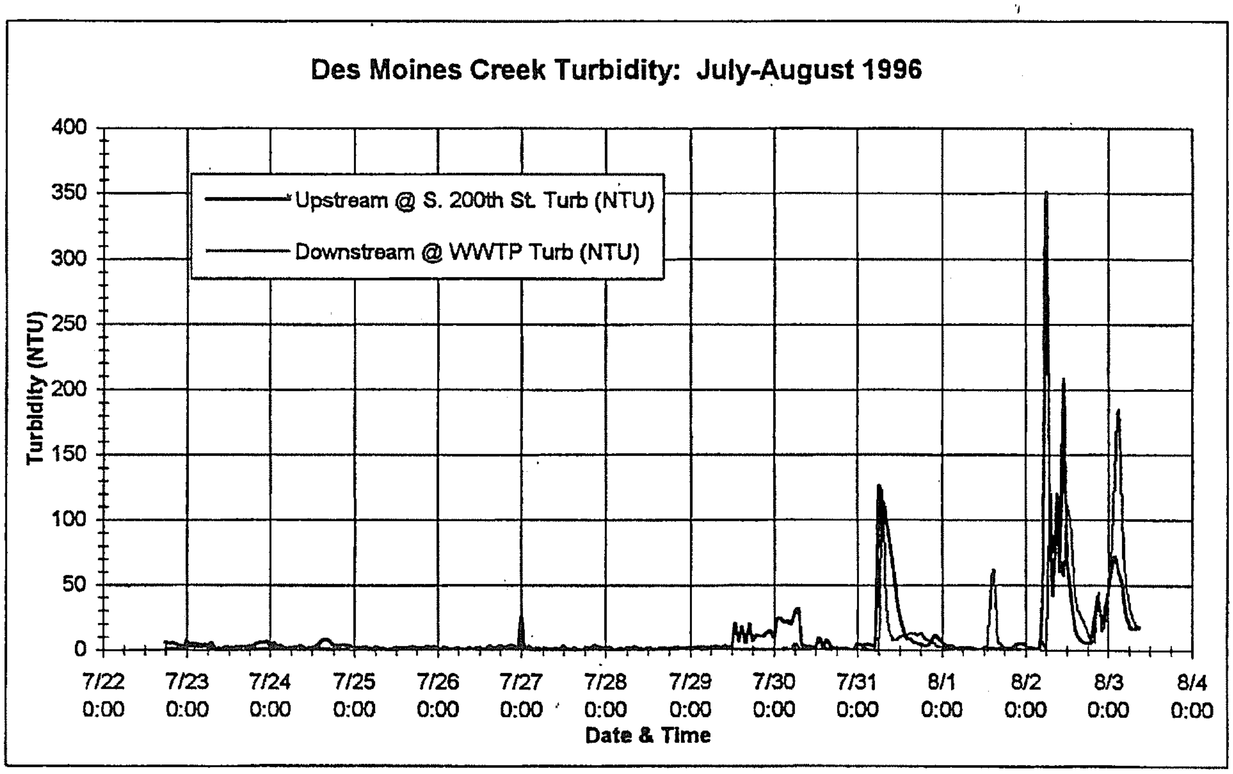
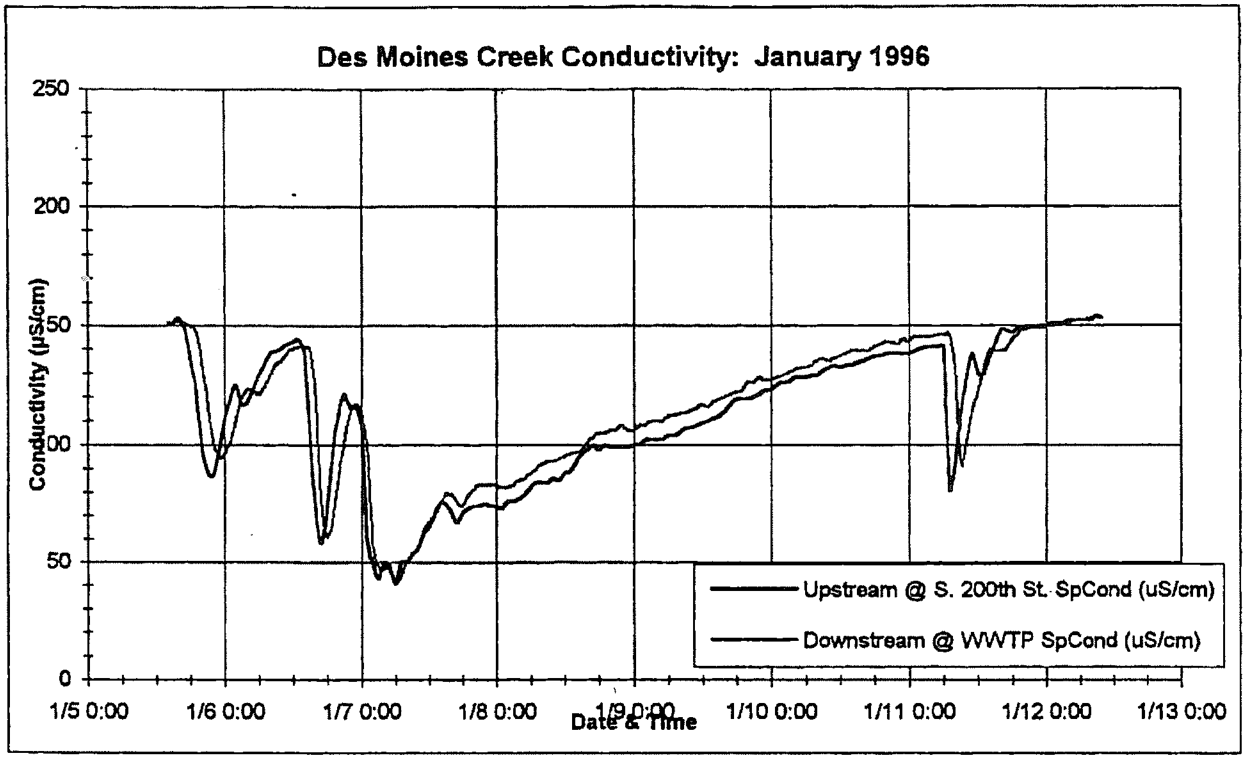


Figure B.4 (continued). Des Moines Creek turbidity at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.



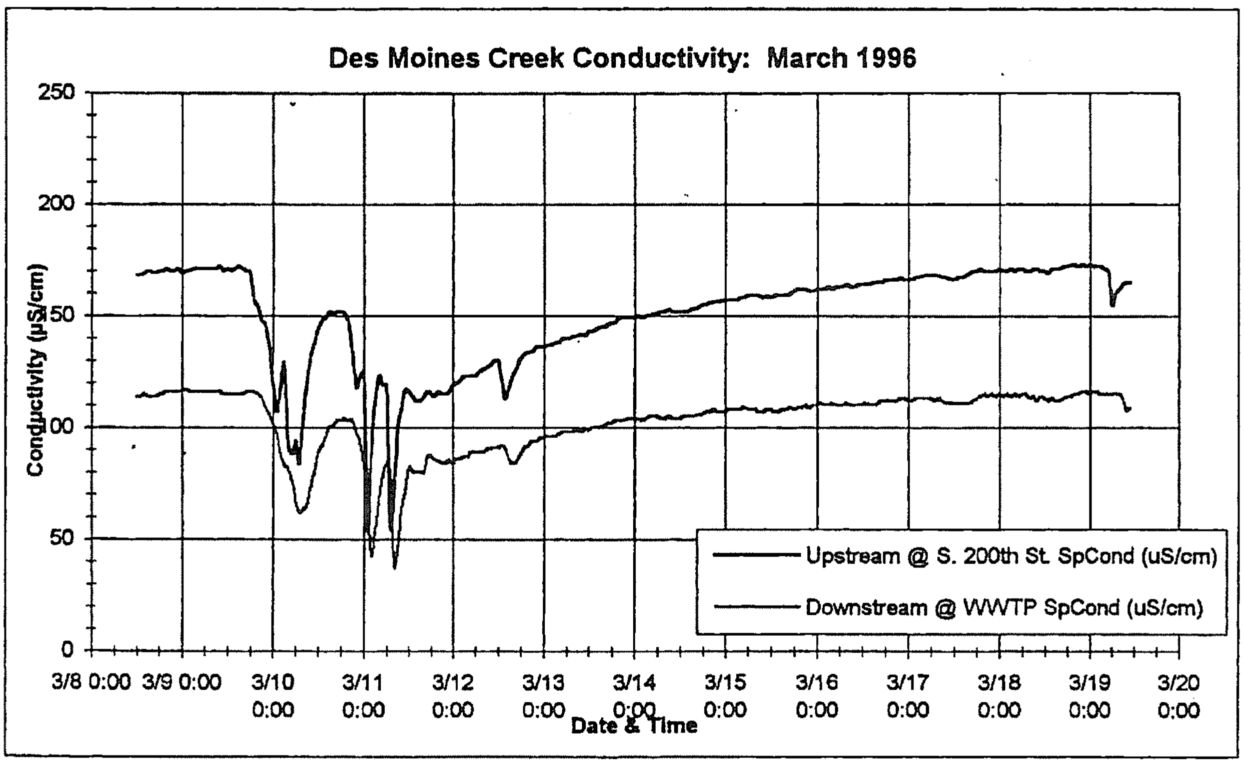
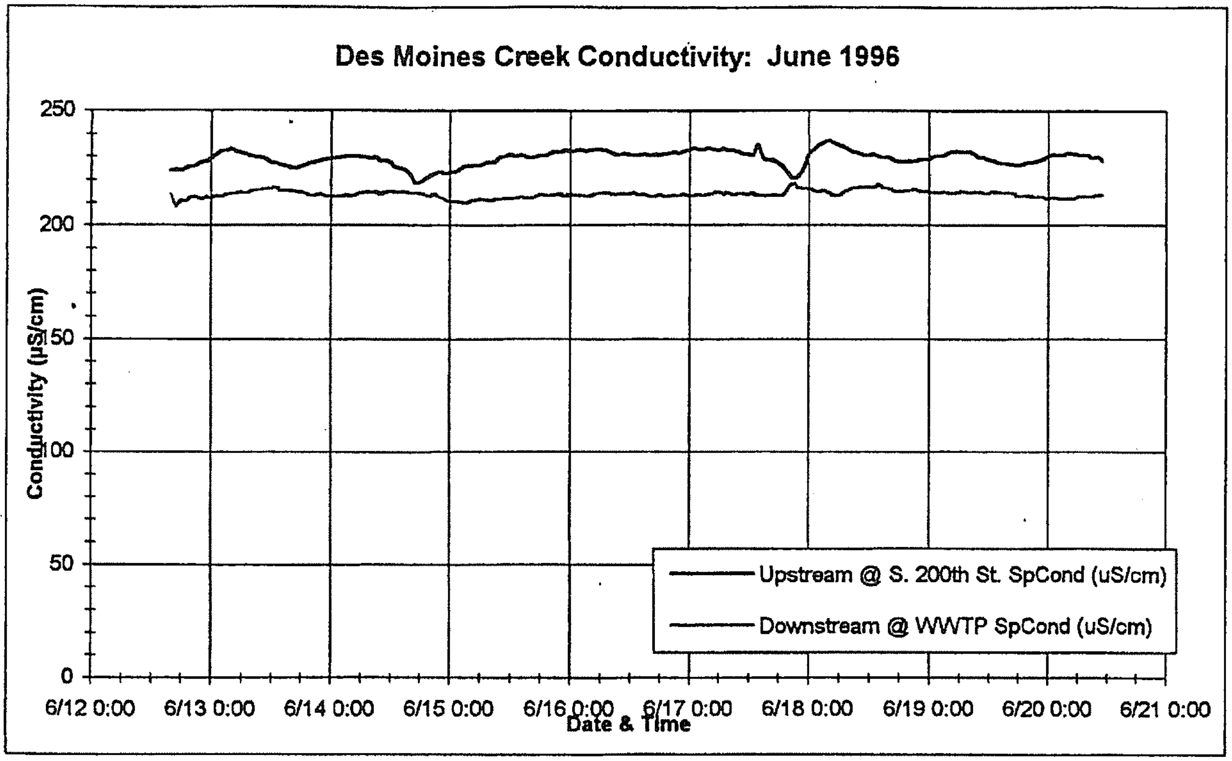


Figure B.5. Des Moines Creek conductivity at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.



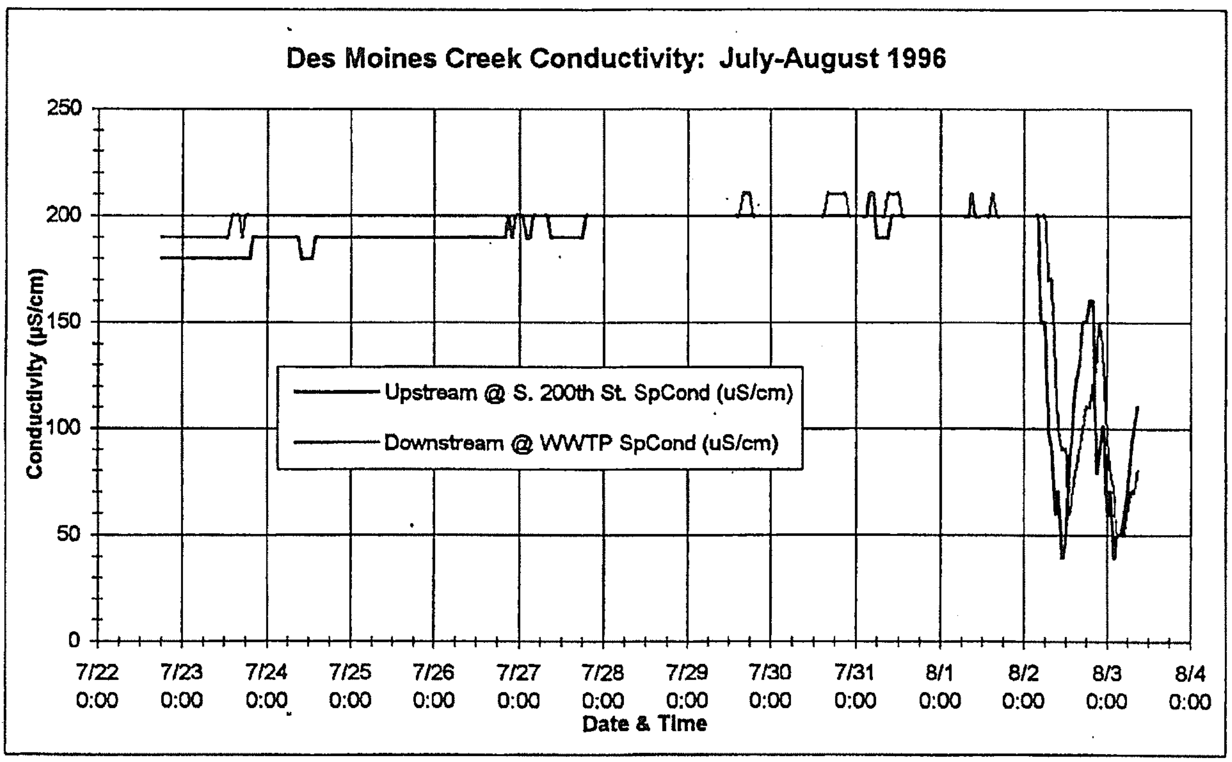


Figure B.5 (continued). Des Moines Creek conductivity at Upstream (S. 200th St.) and Downstream (WWTP) baseflow monitoring stations.

The primary water quality concern for salmonid populations in Des Moines Creek is high water temperature. Water temperatures were evaluated relative to three criteria:

- The upper optimal temperature for salmonid species present in the Creek (14° C) (May Creek Conditions Report)
- Washington State Class AA Standard (16° C),
- A conservative estimate of the upper lethal limit for salmonid species present in the Creek (22° C) (May Creek Conditions Report, 1995).

Water temperatures exceeded ideal levels for salmonids as early as April 7, during an unusually warm period (maximum air temperature 22° on April 7). Temperatures rose from maxima of 13.9° and 13.3° on April 6 to 17.2° and 16.2° on April 7, at the upstream and downstream stations respectively. This rapid temperature response suggests that water temperatures in Des Moines Creek are not well-buffered.

As expected during warmer weather, water temperatures at the downstream station were lower than those measured at the upstream station. Between April 1 and September 6, 1996, the average temperature difference between the two stations was 1.1°C, and the maximum difference between the two reached 3.2°C.

The number of exceedances of criteria and hours per day in exceedance was also notably higher at the upstream station, as described in Table B.7. The data indicate that if fishes are to seek temperature refuge in Des Moines Creek, the reach in the vicinity of the WWTP may provide some relief early in the summer, but by late summer, temperatures in that reach also will become stressful for salmonids.

Table B.7 Temperature Criteria Exceedances, Des Moines Creek Upper and Lower Monitoring Stations (Broken Into Early And Late Summer Monitoring Periods).

April 1-June 30, 1996 (91 days)		**upstream**	**downstream**
Upper optimal temperature for salmonids	Days over 14°C	64	37
	Mean hours/day over 14°C	11.1	8.4
Washington Class AA Standard	Days over 16°C	29	2
	Mean hours/day over 16°C	6.0	5.0
Approximate lethal level for salmonids	Days over 22°C	0	0
	Mean hours/day over 22°C	0	0
July 1-September 6, 1996 (68 days)		**upstream**	**downstream**
Upper optimal temperature for salmonids	Days over 14°C	68	68
	Mean hours/day over 14°C	23.3	20.8
Washington Class AA Standard	Days over 16°C	91	46
	Mean hours/day over 16°C	15.4	11.1
Approximate lethal level for salmonids	Days over 22°C	0	0
	Mean hours/day over 22°C	0	0

The period of greatest concern occurred over eight days from July 23 to July 30. This was a fairly typical hot spell for this region in July or August, with maximum air temperatures in the range of 26-27°C. The overall mean water temperature of 18.3°C and 16.9°C at the upstream and downstream stations, respectively, exceeded the 16°C state standard. Daily maximum water temperatures exceeded 20.5°C at the upstream station, and 18.5°C at the downstream station. Although the lethal limit of 22°C was not exceeded at either station, the sustained high water temperatures during this period created extremely unfavorable conditions for salmonids in Des Moines Creek.

Dissolved Oxygen

Chronically low dissolved oxygen in the outflow from the Northwest Ponds (see Section 6.3.3) causes a continual problem of very low dissolved oxygen in the West Tributary to its confluence with the East Tributary. The dissolved oxygen remains below the WSDOE receiving water standard until South 200th Street. These conditions appear to exist primarily from the spring through the fall, as well as on occasion during the winter when the Northwest Ponds freeze. The data indicate dissolved oxygen values as low as 2mg/L are typical in the West Tributary, and values typically below 7 mg/L in the main stem from the confluence of the two tributaries to the first weir. The County evaluated dissolved oxygen conditions from South 200th Street to the mouth of the creek.

There were no dissolved oxygen (DO) concentration excursions below the 8 mg/L criteria for impairment of salmonids during the four monitoring periods. The absolute minimum observed DO concentrations were 9.1 and 8.5 mg/L at the upstream and downstream stations. DO concentrations in mainstem Des Moines Creek are not a significant concern.

Dissolved oxygen concentrations recorded during the four monitoring periods at S. 200th Street and the WWTP are graphed in Figure B.3. Box-and-whisker plots of these data are graphed in Figure B.6. For an explanation of box-and-whisker plots, please see text box B.1.

Dissolved oxygen concentrations were evaluated relative to three criteria:

- Washington State Class AA Standard (9.5 mg/L).
- The threshold for moderate impairment of developing salmonid embryos (8 mg/L).
- The threshold for severe impairment of developing salmonid embryos (5 mg/L).

Overall mean dissolved oxygen concentrations met all of the above criteria for all four monitoring periods at both sites, except for the downstream station during the July 22 - August 4 monitoring period, where the overall mean value of 9.2 mg/L failed to meet the 9.5 mg/L state standard. These excursions were considered minor and not biologically significant.

A diurnal dissolved oxygen fluctuation was noted at both South 200th Street and the WWTP, suggesting that DO in Des Moines Creek was apparently influenced by conditions in the headwater Northwest Ponds. This fluctuation was observed during all monitoring periods except January, when it is surmised that primary producers were dormant in the Ponds. The fact that the DO concentration at South 200th Street peaked in the mid- to late-morning and hit its low value in the late afternoon suggests a hydraulic residence time of 10 to 12 hours between the Ponds and South 200th Street. The diurnal fluctuation at South 200th Street was extremely damped compared to conditions at the ponds. For example, DO at the pond outlets ranged from 3.5 to 17.5 mg/L over August 17-19, 1996 (Minton, personal communication), while baseflow DO during the July-August monitoring period at South 200th Street ranged only from 9.4 to 10.4 mg/L. As the stream flows through the reach between the Ponds and South 200th Street, it is slowed by three weirs, which also may reaerate the stream as it plunges over the weirs. Reaeration may also occur via groundwater inflows and inflows from the east tributary. This is a significant observation, in that reareation to healthy levels occurs quickly in the mainstem as it leaves the Northwest Ponds, even during nearly anoxic periods in the Ponds.

The DO concentration in January was higher at the upstream station by an average of 3.9 mg/L over the downstream station. No apparent explanation for this observation was found, but it is surmised that decaying plant material in the wetland reach created some oxygen demand. No significant difference in DO concentrations was noted between the upstream and downstream concentrations during the March, June, or July-August monitoring periods; the average measured differences between sites (1.2, 1.1, 0.8 mg/L) were within the accepted range of instrument drift error.

Explanation of box-and-whiskers plots.

A box-and-whiskers plot shows the distribution of water quality data at each site, allowing a graphic comparison of the similarity or difference of the data.

Explanation of Symbols

The horizontal line inside the box represents the median value, and the top and bottom lines of the box represent the 25th and 75th percentiles. The difference between the top and bottom values of the box is defined as the *interquartile range* – the middle 50 percent of the data lies within this range.

Extending from the box are whiskers, which represent 1.5 times the interquartile range beyond the top and bottom of the box. The ends of the whiskers represent the inner fences. The outer fences represent 3 times the interquartile range beyond the edge of the box (no graphic representation is made for the outer fences). Data falling outside the inner fences but within the outer fences are shown as asterisks. Data falling outside the outer fences are shown as small circles – these values represent values which are likely to be outliers, or extreme values which should generally be discounted when comparing data from two sites.

Using the Plots to Compare Data

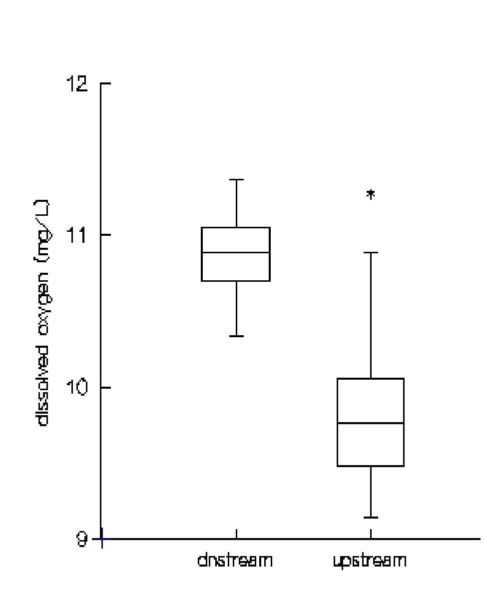
If the boxes from two sets of data overlap vertically, the two data sets are similar; it is very unlikely that a statistically significant difference exists between the data sets.

If the boxes do not overlap, but whiskers overlap substantially, a significant difference may exist between the data sets, but it is not likely that the difference is a strong one.

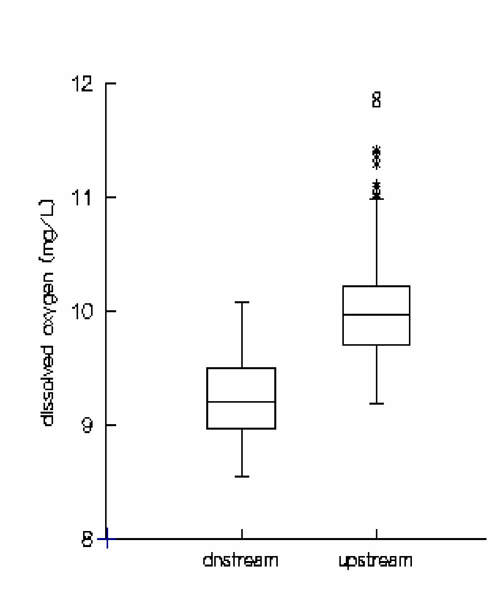
If the whiskers from two data sets have relatively little overlap, or none at all, a strong significant difference exists between the data sets.

It must be emphasized that these plots suggest statistical differences only; if two data sets are deemed to be statistically different, the biological significance of this difference must still be determined by professional judgment.

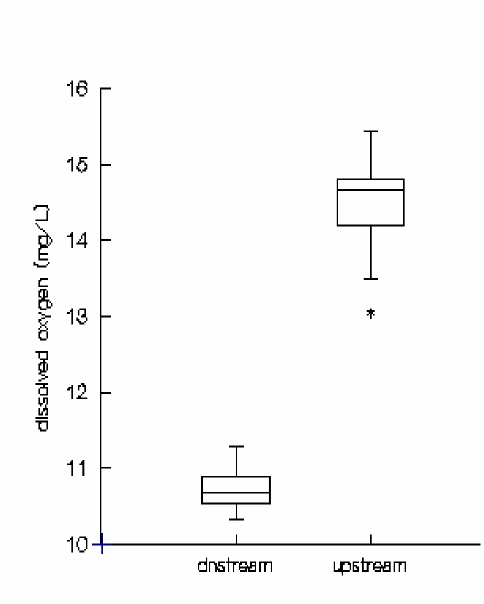
Figure B.6. Box And Whisker Plots Of 1996 Des Moines Creek Baseflow Dissolved Oxygen Data



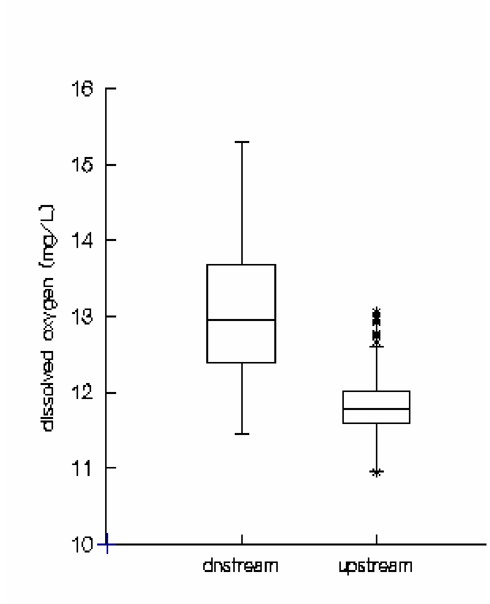
June 1996



July-August 1996



January 1996



March 1996

Turbidity

Baseflow turbidity generally met assumed standards, but highly elevated turbidity during stormflow was a significant concern. The high turbidity during storms was likely a result of a combination of fine sediment entering the water column via surface runoff, bank erosion, and suspension of previously deposited particles in the stream bed. High turbidity suggests high levels of bed scour during storms, and embedding of gravel and cobble substrates as fines settle out when the stream returns to baseflow. These conditions are of particular concern to the stream benthic community and to developing salmon embryos in redds.

Turbidity values recorded during three monitoring periods at S. 200th Street and the WWTP are graphed in Figure B.4. Box-and-whisker plots of these data are graphed in Figure B.7. Due to instrument malfunction, no turbidity data was collected in March 1996.

The Washington State standard for turbidity states that "Turbidity shall not exceed 5 NTU over background turbidity when background turbidity is 50 NTU or less." No historical turbidity data is available for Des Moines Creek. Therefore, for purposes of this analysis, the background turbidity was assumed to be the baseflow value for the upstream station. Based on examination of the three monitoring periods when turbidity was successfully collected, this value was assumed to be 3 NTU; the assumed standard was therefore 8 NTU.

Baseflow turbidity generally met the 8 NTU standard. The standard was severely exceeded during storm events, especially during the January and July-August monitoring periods. Table B.8 lists maximum recorded turbidity values at the upstream and downstream stations for the three monitoring periods when turbidity data was collected.

Table B.8 Des Moines Creek Turbidity Maxima for Three Monitoring Periods.

	Upstream[1]	**Downstream[2]**
January	700*	500
June	38	3
July-August	350	180

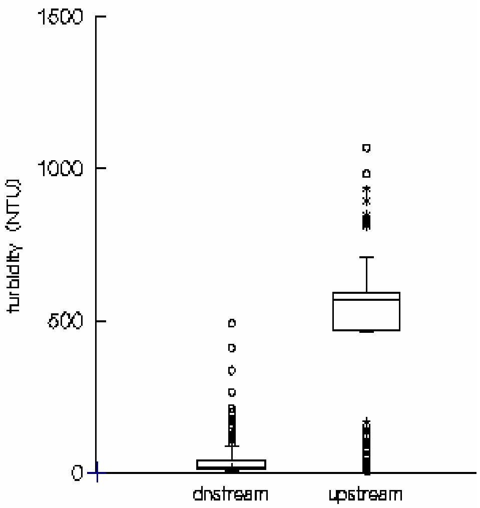
[1] Upstream is at South 200th Street

[2] Downstream is at the Midway Wastewater Treatment Plant.

NOTE: The January upstream value of 700 was estimated after elimination of data collected after instrument malfunction. Units are NTU.

Overall, the data suggests that the stream reach in the vicinity of the downstream monitoring station may be less impacted by high turbidity and concentrations of suspended material. This may be partially due to settling in the slow-moving wetland-associated reach just downstream of the monitoring station at South 200th Street.

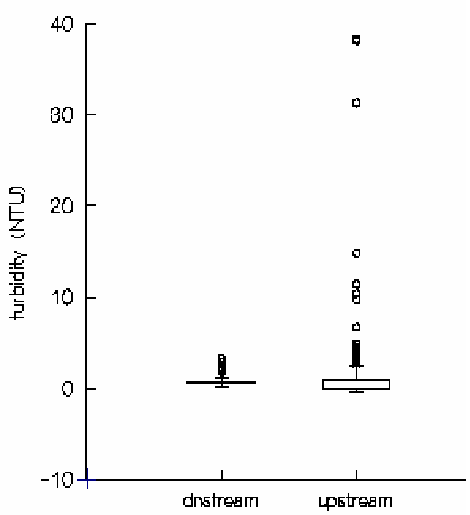
Figure B.7. Box-and-Whisker Plots of 1996 Des Moines Creek Baseflow Turbidity Data



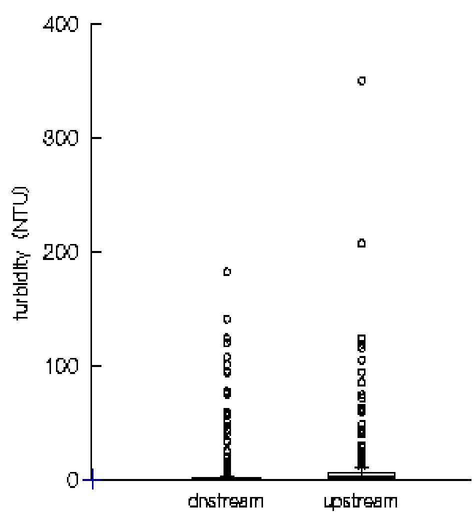
January 1996

(no data available)

March 1996



June 1996



July-August 1996

Conductivity

Conductivity values reflected ranges expected for an urban system, ranging from 150-230 µS/cm for baseflows, and falling to around 50 µS/cm during storms. Conductivity values recorded during the four monitoring periods at S. 200th Street and the WWTP are graphed in Figure B.5. Box-and-whisker plots of these data are graphed in Figure B.8.

Conductivity values at the upstream and downstream stations were very similar during the January and July-August monitoring periods. During the March and June monitoring periods, conductivity values at the upstream station were consistently higher than at the downstream station by approximately 50 µS/cm and 17 µS/cm respectively. This suggests a dilution effect from a source between the two stations.

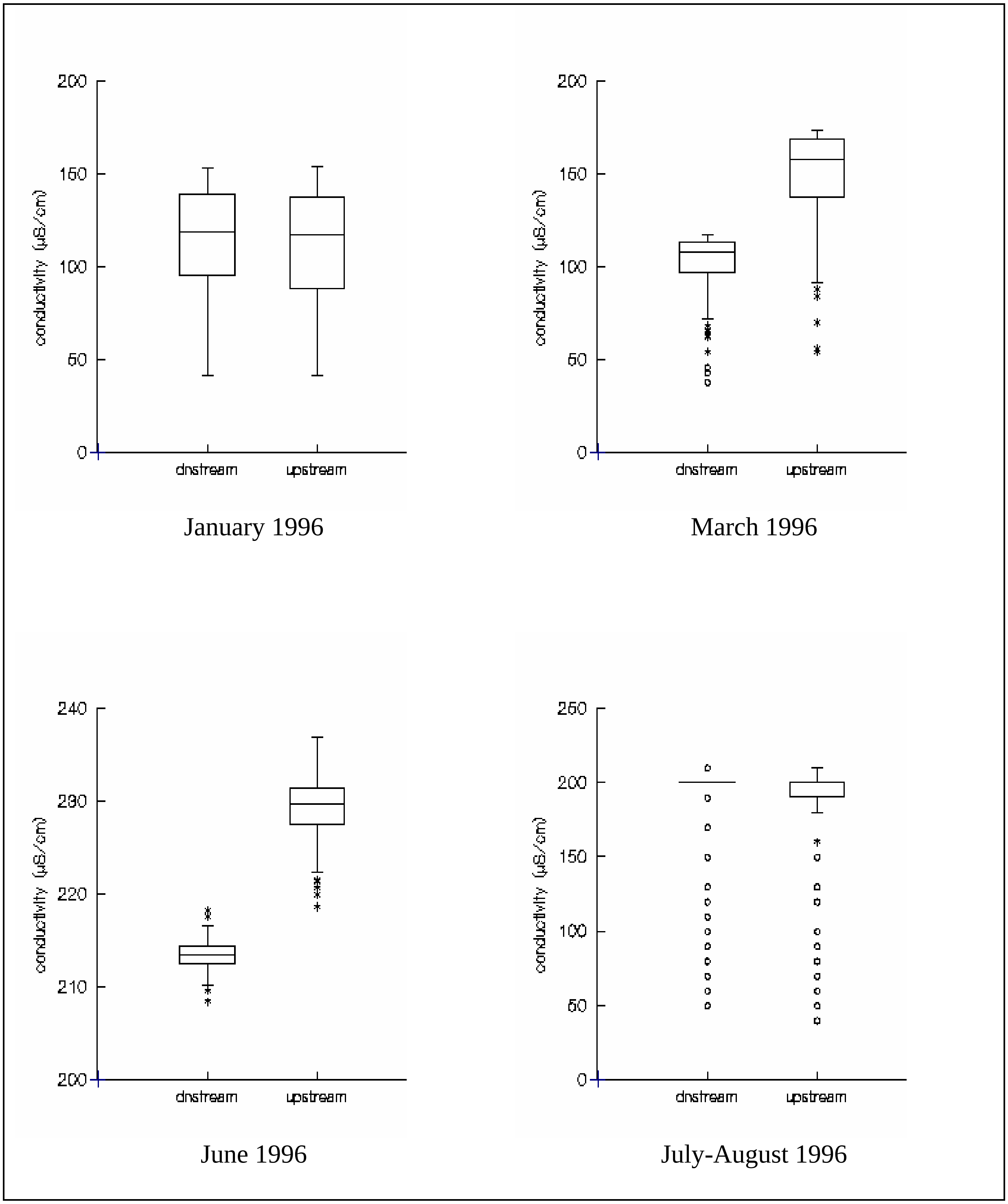
Conductivity values were stable during baseflow conditions. Baseflow values ranged from 120-170 µS/cm in January and March, as dissolved material was apparently diluted in the higher winter baseflow. Baseflow values increased to 200-230 µS/cm during June and July-August, when dissolved materials were more concentrated.

Conductivity was consistently reduced by storm flows. The graph of conductivity values demonstrated a direct inverse to the hydrograph, decreasing sharply during the first flush of the storm, then rising slowly to baseflow values. Oddly, storm flows reduced conductivity to essentially the same minimum of approximately 50 µS/cm in storms during January, March, and July-August, despite different storm magnitudes and different pre-storm baseflow values. As with baseflow, there were no substantial differences between upstream and downstream conductivity values during storms.

Bow Lake Water Quality

In early August 1996, Bow Lake produced a large bluegreen algae bloom. *Anabaena* and *microtoxis* were the dominant bluegreen algaes present. Both genera produce toxic blooms. Many small urban ponds and lakes in King County experienced algal blooms during this same period. It is suspected that nutrients from a summer storm which followed several weeks of hot weather triggered the blooms. The bloom was monitored through the month of August. The lake experienced dramatic dissolved oxygen swings, from 150 percent saturation to nearly anoxic conditions. Dissolved oxygen was measured at the outlet and downstream of Bow Lake (Tyee Golf Course, and S 200th Street). Algae was present in the downstream samples and oxygen levels were near saturation. There were no data to indicate that Bow Lake is impacting the Des Moines Creek by causing oxygen depletion. However, it is likely that the dissolved oxygen concentration is below the WSDOE standard in the upper part of the East Fork. Further investigation is necessary to determine if blooms are an annual or periodic event.

Figure B.8. Box-and-Whisker Plots of 1996 Des Moines Creek Baseflow Conductivity Data



Northwest Ponds Water Quality

The Port of Seattle monitored Northwest Ponds to characterize the function and behavior of the ponds. It appears that the pond has extremes in temperature and dissolved oxygen at various times of the year. Dissolved oxygen (DO) concentrations were low in early February in the most easterly pond during periods of ice cover. This is typical in small ice covered ponds with heavy depositions of organic matter. Dissolved oxygen monitoring in the summer of 1996 indicated very low bottom dissolved oxygen levels in the west and middle ponds. According to the data, this low DO appears to be a chronic summer problem and may exist all year long. The depth of the ponds (3-4 meters) and the trees surrounding each pond minimize wind induced DO replenishment. The eastern pond, conversely, is shallow (0.5-1 meter), with a heavy growth of emergent vegetation throughout the pond, unlike the two westerly ponds which are devoid of vegetation (Minton, 1996). It appears that the low DO from the middle pond is replenished in the east pond by atmospheric re-aeration and primary productivity. However, the primary productivity causes diurnal DO swings in the outlet of the east pond. For example, samples taken on July 30, 1996, indicated that DO saturations ranged from 9.5 mg/l (123 percent saturation) to 1.9 mg/l (21 percent saturation).

Flow measurements and DO sampling in late summer 1996 conducted by the Port indicate that the DO remains low through the low gradient channel in the West Fork after exiting the Northwest Ponds (see Table B.9). Measurements in the West Fork also showed a diurnal swing, except it was delayed from the typical, expected pattern of swings by about 8-12 hours, indicating that the low DO waters exiting the ponds affects the golf course but is aerated by South 200th Street. With current information, it appears that the only the west fork is affected.

Summer temperature patterns, based on limited data, indicate the water heats up as it flows from on pond to the next, with highest temperatures inside and at the outlet of the eastern pond.

Table B.9 Summary of Dissolved Oxygen at Four Locations of Des Moines Creek

Location	Date	Time	Temp (C)	Dissolved Oxygen (mg/l)/ percent saturation
Upstream of west pond	7/29/96	1300	15.0	8.6 / 85 percent
West pond-surface	7/29/96	1630	25.0	3.4 / 41 percent
West pond- bottom	7/29/96	1615	18.0	0.5 / 5 percent
Middle pond- surface	7/29/96	1700	27.0	8.4 / 105 percent
Middle pond- bottom	7/29/96	1715	23.0	2.2 / 26 percent
Eastern pond- surface	7/29/96	1800	29.0	9.5 / 123 percent
Outlet of eastern pond	7/29/96	1530	29.0	10.0 / 130 percent

The Port conducted further temperature and dissolved oxygen analysis during early September along the West Fork. It appears that dissolved oxygen remains low (<3.0 mg/l) throughout the West Fork from Northwest Ponds until aerated at the weirs. East Fork dissolved oxygen was determined to be adequate at >9.0 mg/l.

Pollutant Loading Modeling

The amount of data on specific sources of pollution in the Des Moines Creek basin is very limited. This is not unusual, as limited monitoring dollars are typically focused on stream quality. It is likely the numbers of geese are above what normally might be found in the lake due to shore residents feeding the waterfowl. The recent algal bloom in Bow Lake suggests that it may be a significant source of phosphorus found in Des Moines Creek. Both Bow Lake and the Northwest Ponds are the likely, but natural, causes of low dissolved oxygen and high temperatures found in the upper watershed. Lack of riparian vegetation in the golf course likely exacerbates these conditions, as does relatively poor cover further downstream in the ravine.

The Port of Seattle has been monitoring the quality of stormwater from its outfalls since mid-1994, as required by its NPDES permit. The Port has published two reports summarizing the data with analysis (Port of Seattle, 1995 and 1996). The data generally indicate that the concentrations of pollutants from runway outfalls are lower than from other urban land development like commercial and residential areas. Concentrations of pollutants in stormwater from the area of landside (public access roads and parking) are typical of similar public activities. Comparison of data taken from the first 12 months of sampling (July 1, 1995 to June 30, 1996) to data taken during the previous 12 months (July 1, 1994 to June 30, 1995) indicate that the loading of pollutants has decreased. This decrease is believed (Port of Seattle, 1996) to be due to various actions taken by the Port as described in its Stormwater Pollution Prevention Plan (Port of Seattle, December, 1995).

The level of pollutants from other commercial and residential areas of the basin is unknown at this time, but would be expected to be typical of the same land uses found elsewhere in the Puget Sound Region. Within limits, this observation is being addressed by a second Port study that will be completed by mid-1997. The Port of Seattle is currently conducting a comprehensive study on the relationship between stormwater discharges from the airfield and water quality of Des Moines Creek. The project involves coordinated sampling of stormwater outfalls and stream stations during several storms, the purpose of which is to estimate the relative contribution of pollutants from the airfield to the total quantity of pollutants observed at the same time in the stream. The study is also examining water quality conditions in the Northwest Ponds and its relationship to conditions in the stream.

A unique aspect of the airfield, in comparison to other commercial areas within the basin, is the deicing of aircraft and runways. Samples taken during and/or immediately following deicing chemicals, although in less than 50 percent of the samples (Port of Seattle, 1996). the effect of these chemicals on the creek's biology is not known at this time. This question is being addressed in the Port study described above.

As part of the effort to identify potential future problems, a simple pollutant loading model was developed for this basin. The model utilized standardized contaminant-yield coefficients and was not calibrated for conditions within the Des Moines Creek watershed. Land uses within each catchment were developed specifically for Des Moines Creek.

Care should be taken when interpreting the results of this water quality model. Due to lack of specific calibration this type of model is most useful for predicting the relative change that may occur in each catchment.

Methodology and Assumptions

A simple loading model (Horner, 1990) was used to analyze the current and anticipated annual loadings of key water quality parameters. Annual contaminate-yield coefficients from various land uses were applied to each sub-basin in the study area for total suspended solids (TSS), total phosphorus (TP) , zinc (Z), and fecal coliforms. These parameters are used for modeling because they are well understood, are easily and reliably sampled and they serve as indicators for other pollutants. By multiplying these factors by the area of specific land use, an annual pollutant loading was estimated.

Total Load (Mass) = Land Use Area (Area) * Yield Coefficient (Mass/Area)

Areas of specific land uses were calculated from maps of current and future conditions, as was done for the hydrologic modeling. Future land use assumed maximum buildout based on regional and community plans, zoning, and proposed major development projects (SASA, runway expansions, SR 509). Table B.10 lists the yields coefficients which are based on best available data to simulate pollutant loadings in the study areas.

Table B.10 Pollutant Yield Coefficients

Land use	Total Suspended Solids (kg/ha-yr)	Total Phosphorus (kg/ha-yr)	Zinc (kg/ha-yr)	Fecal Coliform (#/ha-yr)
Forest	26 [1]	0.095[1]	0.020[2]	1.2+E9[1]
Grass	80 [1]	0.010[1]	0.060[2]	4.8+E9[1]
Low Density Single Family-Forest	40 [3]	0.140[3]	0.080[3]	1.4+E9[3]
Low Density Single Family-Grass	60 [1]	0.457[1]	0.080[2]	2.8+E9[1]
Single Family High Density	97 [1]	0.540[1]	0.400[2]	4.5+E9[1]
Multi-family	133 [1]	0.588[1]	0.630[2]	6.3+E9[1]
Impervious/Commercial	242 [1]	0.688[1]	1.000[2]	1.7+E9[1]
Wetland	0	0.000	0.000	

Source:
(1) Horner,R.,1990.
(2) Noveonty, V. and Olem,H., 1994
(3) Reinelt, L. and Horner, R., 1994.

Due to the simplistic nature of the model, a number of generalizations and assumptions were made. Key assumptions are described below, since they potentially influence the results. The subcatchments were aggregated based on their location to facilitate the discussion of the results. For example, Bow Lake Subcatchments includes 1,2, and 3 (see Table B.11).

Table B.11 Aggregated Subcatchments in the Des Moines Creek Basin

Subcatchment Name	***Aggregated Subcatchments***
Bow Lake	1,2,3
Tyee Pond	4,5,6
NW Ponds	7,8,9,10,11,12
Des Moines Creek park	13,14,15
SE Sea-Tac	15,16,17
North Branch Ravine	19
Upper Ravine	20
Lower Ravine	21
Central Des Moines	22
Sea-Tac Airport	23,24,25,26,27

NOTE: For subcatchment locations see Figure A.1.

- Since the majority of impervious area is commercial or industrial, this land use was modeled as a commercial loading. Note that State Route (SR)-99 and SR509 are included in the commercial category as well as the airport runways (due to the traffic).
- The load coefficient for all parameters from "wetland" land use was set to zero, because wetlands produce highly variable pollutant loadings. Contributions from "lake" land use are assumed to be negligible and therefore equal zero.
- The grass category was assumed to be predominately open grass areas and was assigned a loading coefficient accordingly. This may under represent phosphorus loadings from fertilizers, especially for managed turf areas such as the golf course.
- Historic pollutant loadings are not accounted for since this model calculates the potential for an annual load.
- All loadings should be compared on a relative basis, not as absolute values.
- Future land use conditions are based on total buildout, SASA, third runway, and SR509 expansion.
- Both current and future conditions exclude the area that drains to the IWS, since this water does not enter the creek but is discharged directly to Puget Sound.

Results

This section discusses the results of the current and future conditions modeling and then compares them to determine the areas of greatest change. These modeling results analyze the potential for a land use to contribute loadings. Results do not take into account any management practices or mitigation currently in place. but are useful in comparing charges in pollutant loading that could be expected in the future.

Total annual loads are estimates of the total amount of pollutants reaching the stream. Unit annual loads show these amounts on a unit area basis. Unit loads can be used to compare subcatchments on an equivalent basis. For example, two subcatchments may have the same total annual load but different acreages. By comparing total unit loads, the bias of the larger land area is avoided, and the relative loading from each area can be compared.

Under current conditions, southeast Sea-Tac and the three upper subcatchments (Bow Lake, Northwest Ponds, and the airport), are believed to contribute the greatest amount of pollutants. The Tyee Pond subcatchment is close behind these subcatchments in quantity of pollutants, probably due to the amount of commercial activity in this area. As expected, the areas of the highest development levels, with a significant percentage of impervious surface and multifamily residences, produce the greatest contribution of pollutants. The Des Moines Creek Park subcatchment currently has the least amount of development, being mostly grass and forest, and it contributes the least amount of pollutants. It is interesting to note that all eleven subcatchments have relatively high fecal coliform loadings.

Under future conditions again Bow Lake, NW Ponds, SE SeaTac and the Airport are the subcatchments expected to contribute the highest loadings to the creek. The subcatchments expected to contribute the lowest loading of pollutants are Central Des Moines and North Tributary Ravine subcatchments.

With unmitigated development, water quality is expected to degrade in all of the sub-basins except Airport North, but will degrade most dramatically in those sub-basins with the greatest increase in projected urbanized areas. Des Moines Creek Park shows the greatest expected increase, particularly with zinc (85 percent increase) and total phosphorus (81 percent). Zinc, phosphorus, and total suspended solids are expected to increase across the basin. Fecal coliforms are actually expected to decrease in some areas, as grasses and forested areas are developed, particularly in the Tyee Pond and SE SeaTac sub-basins. With maximum buildout the likelihood of water quality problems becomes more evident.

Figure B.12 shows the percent change in total load from current to future scenarios. The approximate order in which sub-basins will suffer from future unmitigated water quality degradation, from least to greatest change is shown in the following list:

Table B.12 Percent Change in Total Load from Current to Future Scenarios

Least Change	Bow Lake
^	Lower Ravine
^	North Branch Ravine
^	Airport Runway
^	SE SeaTac, Tyee Ponds
^	NW Ponds
^	Central Des Moines
^	Upper Ravine
Greatest Change	Des Moines Creek Park

Des Moines Creek Park will have the greatest change in its water quality because it is planned to have a 64 percent increase in impervious land uses (commercial/industrial/roads) and a 8 percent increase in multifamily land use. Upper Ravine, the sub-basin with the second largest increase is expected to undergo a 20 percent increase in impervious and a 19 percent increase in multifamily.

If water quality mitigation is not implemented, the concentrations of pollutants will increase and could be a greater concern for aquatic life, particularly copper & zinc which currently exceed water quality standards. Fecal levels, while presenting possible human health issues, are not expected to produce serious impacts to aquatic life.

APPENDIX C - FISHERIES ANALYSIS

Limiting Factor Analysis

The habitat requirements of the salmon and trout species in Des Moines Creek are discussed below and in the accompanying tables. From these requirements, and data and observations collected in recent inventories, the following factors potentially limiting salmon and trout production in the Creek were identified.

Barriers to Upstream Migration of Adult Fish

1) The concrete box culvert (4 ft. wide x 6 ft. high x 225 ft. long) located at the upstream end of the Park Reach (crosses under Marine View Drive). This culvert was built in 1922-1923 when the canyon was filled to replace a bridge that spanned the creek (Draper 1975; Kennedy and Schmidt 1989). Although not a complete barrier (adult coho, searun cutthroat trout, and steelhead have been observed upstream of it), this culvert is a major impediment to upstream migration. During a recent inspection, with a stream flow of approximately 10.0 cfs, the water depth within the culvert was less than six inches. This shallow depth would prevent adult salmon from swimming through the culvert. The water velocity in the uppermost 100 ft of the culvert was 7–8 fps. Water velocities of this magnitude over this distance are at the upper limit of swimming ability for coho, searun cutthroat trout and steelhead, and exceeds the swimming ability of chum and pink salmon (Bell 1986). To ensure that migrating adults can reach spawning habitat in the upstream reaches, water depth and velocities in this culvert should be adjusted.

2) A series of concrete weirs and fishways are located in a short, high-gradient section of stream at the upstream end of the Plant Reach. The hydraulics of these weirs should be investigated to insure that fish passage is maintained. The weirs themselves are low and perhaps passable by coho, steelhead, and possibly searun cutthroat trout, provided that the pools in front of the weirs are sufficiently deep enough. Chum and pink salmon are poor jumpers (Powers and Orsborn 1985) and would probably be blocked here if the fishways were passable. These weirs do provide critical aeration which improves summer high temperatures and lowered dissolved oxygen levels. Any modification or elimination of these weirs include consideration of preserving the aeration/cooling function they currently provide.

Spawning and Incubation Habitat

The quantity of spawning gravel does not appear to be a limiting factor. There is sufficient gravel in the channel below the treatment plant, and numerous gravel recruitment sources to the channel, in a range of sizes suited to the needs of all salmonids using the stream. The high-energy flows that frequently occur in Des Moines Creek could limit incubation success through deep scouring of egg pockets as was documented during the 1995-96 winter season. Scour monitors in place during the 1995-96 winter flood season indicate that deep scour currently occurs over large portions of the channel during major flow events.

Habitat for Rearing of Post-Emergent Fry

The availability of channel margin habitat is likely to be a limiting factor in Des Moines Creek. Upon emergence, the juveniles of stream-rearing salmonids such as coho salmon, searun and resident cutthroat trout, and steelhead move quickly into areas along the channel margins where water velocities are low. They stay there for the first few weeks until they can cope with stronger currents. Then they move out into the main channel to seek territories for summer rearing. The juveniles of chum and pink salmon migrate quickly downstream to saltwater upon emergence and do not require stream margin habitat. Although it is difficult to quantify stream margin habitat, the stream generally lacks quiet or slack water areas along the majority of the channel.

Summer and Winter Rearing Habitat for Stream Dwelling Juvenile and Resident Salmonids

A recent habitat survey of Des Moines Creek (Resource Planning Associates et al. 1994) found the most common habitat type to be long shallow riffles, with pools being few and far between and most of those being shallow and relatively high in average water velocity. Of the 133 residual pools identified in the 1994 survey (i.e., those that would have water at zero flow), more than half had residual depths of one foot or less.

Stream-rearing salmonids (i.e., coho juveniles, adult and juvenile cutthroat, and steelhead juveniles) generally prefer slow, deep pool habitats, especially plunge pools and lateral scour pools associated with wetted root wads, large woody debris complexes, and boulders collectively referred to as "resisted lateral scour" habitats (White 1991). These pools should have residual depths greater than one foot and water velocities ranging between 0.33–2.0 fps. Cutthroat trout and steelhead will also utilize deep pocket-water types of habitat units where water velocities are tolerable. If these habitat types also have bottom substrates of cobble and boulder, where fish can move within the interstices, they will also serve to provide in-channel overwintering shelter against high winter flows. Des Moines Creek has an almost total lack of habitat units with these desirable characteristics, as revealed by the recent habitat survey (Resource Planning Associates et al. 1994).

As peak flows in Des Moines Creek have become higher and more frequent, the stream has responded by downcutting its channel in the Ravine Reach and widening and becoming more shallow in the Plant Reach. As this has happened, habitat complexity has decreased and shifted to a high proportion of shallow, swifter habitat types. The present high-energy runoff of the stream essentially prevents it from forming the habitat types preferred by the fish for summer and winter rearing.

Availability of Food

Another consequence of a flashy flow regime is that aquatic invertebrate communities, depleted by the high-intensity runoff, do not have time between runoff events to recover to healthy levels, thus leading to a decline in the food supply of the fish. Wisseman (1994) concluded that such a decline has indeed occurred in Des Moines Creek where he found benthic invertebrate communities to be severely stressed. Therefore, the availability of food may be another limiting factor for fish production in the creek.

Wisseman (1994) also suggested that some of the stresses on the benthic invertebrates may be due to more than just flow impacts on habitat. He implicated episodic toxic effects, i.e., spills of toxic materials that travel downstream or storms that mobilize toxic materials that are already present from previous spills. Several jet fuel spills have occurred in the past which caused reportable fish kills in Des Moines Creek (Taylor 1974; Kittle 1986).

High Summer Stream Temperatures/Low Dissolved Oxygen

Recent information (1996) indicates temperatures and dissolved oxygen levels discharging Northwest Ponds to be of concern. However the weirs located on the Tyee Golf Course above S. 200th Street provide enough surface contact aeration to reduce the impact from the west tributary to levels tolerable by the resident cutthroat trout which use this portion of the Creek.

Reach-by-Reach Prescriptions to Relieve Major Limiting Factors.

The flow regime of Des Moines Creek (i.e., both high and low flows) and the simplified habitat are likely the principal factors limiting salmonid production in the stream. Although it is impossible to return the basin and stream channel fully to a pre-development state, it is possible to improve the stream significantly enough to make a considerable difference in fish populations. Once measures have been taken to stabilize flows, other more specific instream habitat improvement measures can then be undertaken with a greater probability of success.

The physical parameters associated with spawning and rearing habitat for salmonid species that inhabit Des Moines Creek were compiled to assist in identifying the limiting factors in the various reaches (see Tables C.1 and C.2). This information, which was obtained from numerous sources, provides the basis for identifying specific features that could be changed to potentially increase fish production in these areas.

Table C.1 Physical Parameters Associated with Spawning Habitat of Des Moines Creek Salmonids [1]

	SPECIES				
Parameter	**Coho**	**Chum**	**Pink**	**Searun Ct**	**Steelhead**
Timing (month) Location [2]	O, N, D, J, F	N, D, J	O, N See footnote	J, F, M	J, F, M
Gravel diameter (in) Percent fines [3]	0.5 to 5.0	0.5 to 6.0	0.5 to 4.0 See footnote	0.1 to 2.5	0.5 to 5.0
Water depth (in)	4 to 24	8 to 43	6 to 20	6 to 18	6 to 28
Velocity, (fps)	1.0 to 2.9	0.6 to 3.7	1.0 to 4.5	0.5 to 2	1.2 to 2.9
Temperature C^o (F^o)	4.4 to 9.4 (40 to 49)	7.2 to 12.8 (45 to 55)	7.8 to 12.8 (46 to 55)	6 and up (42.8 up)	3.9 to 9.4 (39 to 49)
Egg pocket depth (in)	7 to 15	3 to 20	6 to 20	3.5 to 12	8 to 18
Redd area (ft^2)	30	24.7	11.8	1 to 10	47 to 58
Area per female (ft^2)	90 to 126	99	16 to 21.5	No inf.	No inf.

1) Data compiled from Bell (1986); Bjornn & Reiser (1991); Burner (1951); Collings (1974); Giger (1973); Heard (1991); Hourston & MacKinnon (1957); Hunter (1973); Orcutt et al. (1968); Reiser & White (1981); Salo (1991); Sandercock (1991); Smith (1973); Thompson (1972); van den Berghe & Gross (1984); Vaux (1968); Wells & McNeil (1970); and Williams, et al. (1975).

2) n general, gravel areas where either upwelling or downwelling currents operate are suitable for salmonid spawning. Vaux (1968) related this to the topography of the streambed, pointing out that upwelling occurs where the streambed is concave (e.g., the downstream end of a riffle) and downwelling occurs where the streambed is convex (the tailout of a pool). Many salmonid species prefer areas where downwelling occurs, i.e., pool tailouts and the leading edges of point bars (Bjornn & Reiser 1991), but chum salmon often choose upwelling areas (cited in Heard 1991).

   Nearness to cover may be a factor in the selection of spawning sites by some species (Bjornn & Reiser 1991). Cover protects fish from disturbance and predation, and also provides shade. Cover can be provided by overhanging vegetation, undercut banks, submerged rocks and logs, floating debris, deep water, surface turbulence, or foam and bubble cover (Giger 1973).

3) This graph shows the significant drop in embryo survival that occurs when the percentage of fine sediment deposited in redds exceeds 20 percent (Bjornn & Reiser 1991 and references cited therein). The amount of fine sediment deposited, in turn, depends on flow conditions in the stream and the size and amount of sediment being transported.

Table C.2 Physical Parameters Associated With Stream Rearing Habitat Of Des Moines Creek Salmonids [1, 2]

Parameter	SPECIES Coho	Chum	Pink	Searun Ct	Steelhead
Summer water temp (C^{o})	12.2 - 13.9	N A	N A	8.9 - 12.2	10 - 12.8
Upper lethal temp (C^{o})	26.1	N A	N A	22.8	23.9
Water velocity (fps)[3]	< 2.0	N A	N A	< 2.0	< 5.0
Pool area (percent of reach)	40 - 60	N A	N A	40 - 60	40 - 60
Residual pool depth (ft)	> 1.0	N A	N A	> 1.0	
Substrate	Boulder, cobble, LDW, etc.	N A	N A	Boulder, cobble, LWD, etc.	Boulder, cobble, LWD, etc.
Habitat types[4]	Deep plunge/ lateral scour/ backwater pools	N A	N A	Deep plunge/ lateral scour pools; pocket water	Plunge/lateral scour pools; pocket water; low gradient riffles

1) Data compiled from Bell (1986); Bisson et al. (1988); Bjornn & Reiser (1991); Brett (1952); Bustard & Narver (1975a, 1975b); Hartman (1965); Hunter (1973); McMahon (1983); Nichelson et al. (1992); Olson (1995); and White (1991).

2) The tabulated parameters describe summer rearing habitat. For overwintering, stream dwelling salmonids (juvenile coho, juvenile searun cutthroat trout , juvenile and adult resident cutthroat trout, and steelhead) move into interstices within boulder and cobble substrates of deep, slow pools; also undercut banks, off-channel ponds, side channels, and alcoves (which are slack-water areas along the channel margin separated from the main current by streambanks or large channel obstructions such that they remain quiet even at high flows).

3) Juvenile and resident cutthroat trout and juvenile coho prefer to hold station in water that runs about 0.25 to 0.5 fps but will feed into water that runs up to 2 fps. Juvenile steelhead will tolerate somewhat faster water for holding positions and will feed into currents up to about 5 fps.

4) These are preferred summer rearing habitats. See text for more complete descriptions. For overwintering habitat, see footnote (2).

Plateau Reach Above South 200th Street

Few limiting factors were immediately obvious in this reach. Water quality data suggests that elevated temperatures and lowered dissolved oxygen levels in this reach should be stressing fish populations, although field surveys show large fish residing in this reach. As with other portions of Des Moines Creek, there is a lack of large woody debris in this reach. The habitat is mostly low gradient riffles with glides and small lateral scour pools.

The fish in this reach are primarily cutthroat trout. Actions that would help these fish would be to stabilize flows (i.e., primarily reduce high flows) and to provide additional pool depth and instream cover. Additional detention within this part of the basin has appeared in all prior basin management plans and should be a key element in any new plan.

Plateau Reach Below South 200th Street

The present flow regime of Des Moines Creek is likely a principal factor that limits salmonid production in the stream, particularly in this reach. Although it is impossible to return the basin and stream channel fully to the pre-development state, it is possible to nudge the stream significantly enough in that direction to make a difference. If adequate flow control were achieved, flow velocities may slow enough to allow other habitat improvement measures to take effect. That portion of the basin draining into the Plateau Reach will be the most crucial to achieving these goals. Once measures have been taken, other more specific instream habitat improvement measures can be undertaken in downstream reaches with a greater probability of success.

Ravine Reach

The major limiting factor in the Ravine Reach appears to be lack of deep, slow pools for summer and winter rearing. Although resident cutthroat trout currently use this reach, their small average size and relatively low numbers indicate that habitat may be limiting. If flows can be moderated, the preferred types of pool and pocket-water habitat units could be created by placement of appropriate structures. These pools would be plunge pools and lateral scour pools associated with root wads, boulders, and large woody debris complexes, with the large majority having residual pool depths of one foot or more.

Given the tightly confined nature of the channel within this reach and the need to protect pipelines buried along most of the right bank of the stream, there is little room to create off-channel winter rearing areas. Winter rearing habitat must be created entirely within the channel. Because of the pipeline, there is a considerable quantity of boulders and large rock that could be repositioned or placed in the channel to create additional winter rearing substrate or pocket-water.

Other restoration efforts in this reach would be the placement of gravel-trapping structures to induce the refilling of segments where the stream has scoured out all loose sediment. This would help offset the loss of spawning habitat and improve the amount of lateral habitat in these segments for the rearing of post-emergent fry.

Treatment Plant Reach

As in the Ravine Reach, the principal limiting factor in this reach appears to be lack of deep, slow pools for summer and winter rearing. Again, the desired types of pool and pocket-water habitats could be created by appropriately placed instream structures. A pool-to-riffle ratio of 1:1 is advisable, with the majority of the pools having residual depths of greater than one foot.

Because this reach is lower gradient and less confined than the Ravine Reach, there are terrace and floodplain areas and some segments where secondary channels may have existed. Restoring these areas so that they function dependably as bypass or overflow channels during winter high flows would increase the amount of overwintering habitat available in this reach.

A notable feature of this reach is the canopy of foliage provided by the virtually pure stands of alder growing on the terraces. While this provides shade and a source of large woody debris for the stream, it could be improved by increasing the number of conifers in these stands. This could be accomplished by a program of conifer planting, not only in this reach but all along Des Moines Creek.

Park Reach

This reach, with its many long, uniform deposits of gravel, resembles a spawning channel that might be deliberately created for fishery enhancement. Instream work in this reach should focus on creating pools for holding adult fish and stabilizing streambed gravels. The majority of this reach should be left for use by spawning chum and especially pink salmon, which often seek out such uniform reaches in natural streams. This would also be a good reach in which to promote a “watchable wildlife” program for the viewing of naturally spawning salmon.

APPENDIX D - ENGINEERING & LAND USE ANALYSES

Methods

Given the buffered, undeveloped nature of the Des Moines Creek stream corridor, major flooding problems were not anticipated, so detailed floodplain modeling was not performed. To determine where known problems related to flooding or infrastructure existed, Project Management Team members were interviewed. In addition, an evaluation was conducted of all locations of road crossings over Des Moines Creek. Capacities of each of these structures were computed using standard Federal Highways Administration culvert and bridge methodologies. A detailed survey of the stream and adjacent and intersecting roadways was not conducted; however, existing engineering drawings were utilized to supplement field observations whenever possible.

The identified problems were then evaluated for their regional significance, and only those considered regionally important were considered for solution development. Where solutions are recommended in this report, estimated costs are based on standard King County preliminary project construction cost estimates. These estimates reflect design and construction costs, including right of way and overhead.

Results

The analysis of capacities of road crossings suggested that the two major arterial crossings of Des Moines Creek -- South 200th Street and Marine View Drive -- are adequate to convey flows through at least the 25-year level for both current and future land use conditions. In addition, the access road bridges at the Midway Sewer District's treatment plant also appear adequate for anticipated current and future flood flows up to and including the 25-year event.

There are several crossings of minor tributaries that are undersized and should be upgraded when possible. These tributary crossing problems are well known to the local jurisdictions, and in some cases, specific studies have been initiated to determine how to address them. The minor tributary problems are considered local problems, and have not been specifically analyzed as part of this basin plan. They are, however, included in the problem table in Section 3.

Planning and Land Use Analysis

Planning and land use analysis in this type of watershed planning effort is used to provide accurate current and future land cover information for hydrologic and water quality models. Information is needed regarding the location of land covers which produce negative impacts to the stream system such as impervious areas, landslide hazard areas and erosion areas. Information is also needed about the location of land covers which benefit the stream system, such as wetlands and riparian buffer zones. This land cover information is needed for existing conditions in order to accurately calibrate the model, and it is needed for future conditions to allow for accurate predications. While land use and planning analysis is often used to provide recommendations for future land uses, no attempt to develop recommended modifications to future land use plans was made in this study.

Current and Future Land Use

Current Land Use

Maps of current land use were prepared by utilizing aerial photography and, to a lesser extent, satellite imagery. Aerial photographs of the project area were examined and an overlay was prepared which classifies the existing land cover into one of 11 different land use categories (see Table D.1). These classifications are based on what is actually on the ground, rather than on the zoning or land use classification, and are primarily based on the amount of impervious area which is evident.

Table D.1 Land Use Categories and Impervious Area Assumptions

Category	Approx. Impervious Area [1]	Effective Impervious Area [2]
Impervious	90%	85%
Multifamily	65%	48%
High Density SFR	40%	25%
Med. Density SFR	20% (not used in Des Moines)	10%(not used in Des Moines)
Low Density SFR	8%	4%
Grass/Shrub	0%	0%
Forest	0%	0%
Open Water	0%	0%
Wetland	0%	0%
Quarry/Landfill	0%	0%
Clearcut	0% (not used in Des Moines)	0% (not used in Des Moines)

1) Approximate Impervious Area is the actual impervious area as would be estimated from aerial photographs. These are average values which have been developed from previous studies and are fairly constant across the County.

2) Effective Impervious Area is the value used for hydrologic modeling, and reflects the fact that not all impervious area contributes immediately to runoff. These are average values which have been developed from previous studies and are fairly constant across the County.

Future Land Use

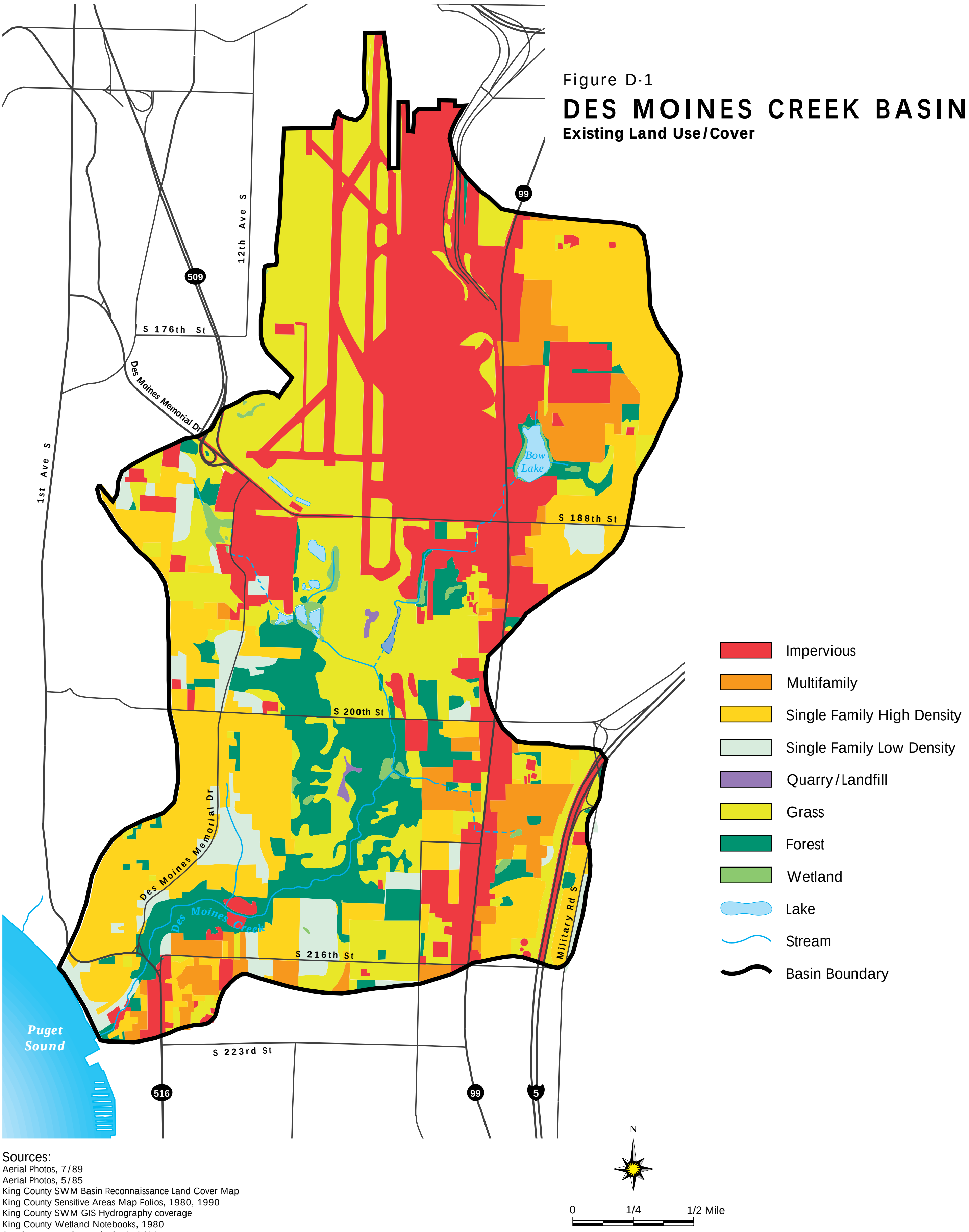
Future land uses within the cities were projected by assuming that jurisdictions would eventually develop to the levels predicted in their Comprehensive Plans. This is a conservative assumption since, if the cities build less than they project, the impacts to stormwater runoff will also be less. Using the most recently published Comprehensive Plans for each city, the specific development requirements and use restrictions for each land use classification were examined to determine what level of impervious area and vegetation retention would be on the ground after development. Given these limitations, the land uses for each city were then assigned to the most appropriate land cover category.

Due to the coarse scale of the King County Comprehensive Plan relative to the small area of the basin located in King County, use of the comprehensive plan for predicting future land use was not a suitable technique. Instead, the zoning for this area was used to estimate future land cover and land density. The two zones in this area, M-P and RS-7200, were assigned the future land use categories Impervious and High Density Single Family, respectively.

Figure D-1

DES MOINES CREEK BASIN

Existing Land Use/Cover



October 1997

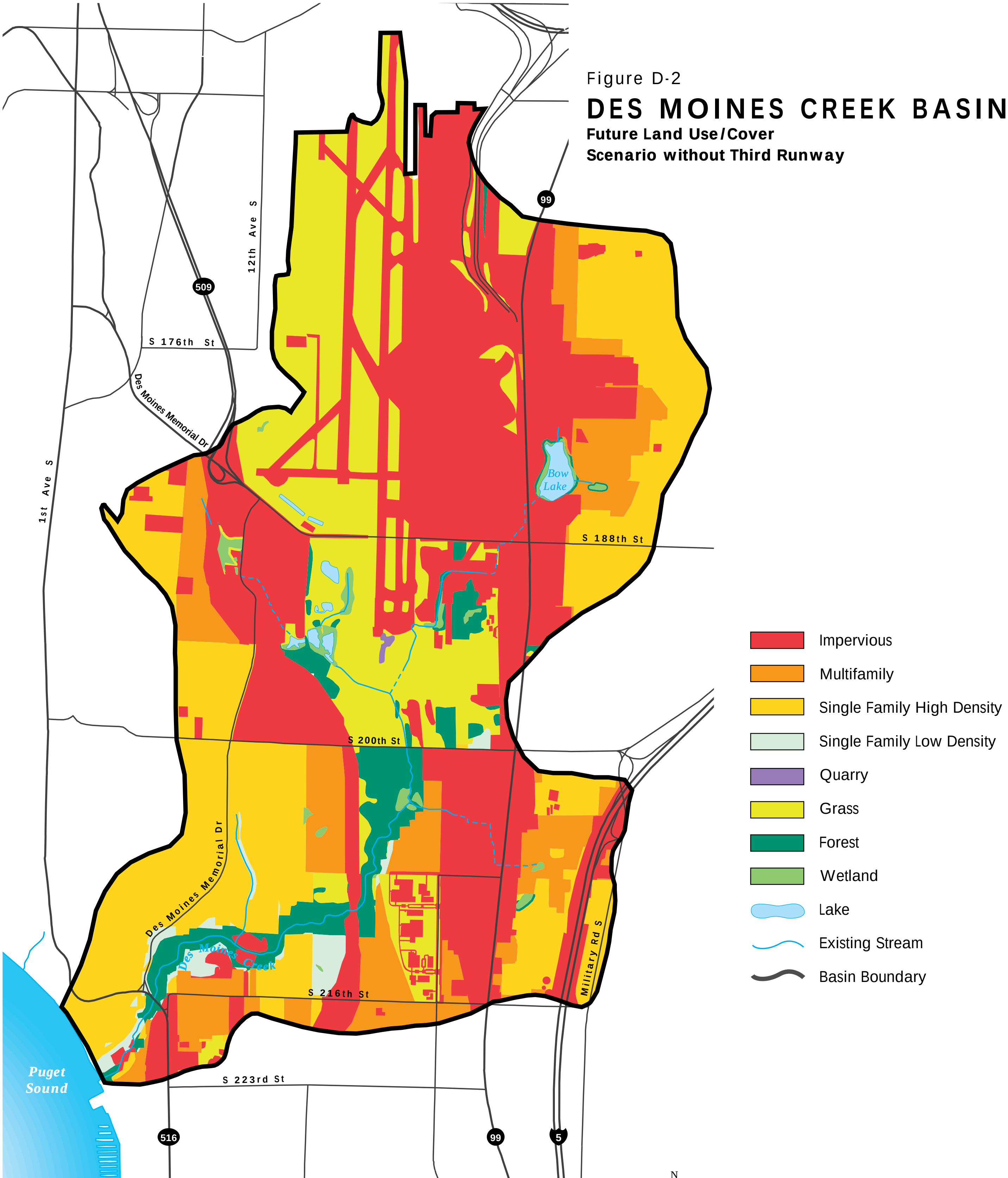
Sources:
Aerial Photos, 7/89
Aerial Photos, 5/85
King County SWM Basin Reconnaissance Land Cover Map
King County Sensitive Areas Map Folios, 1980, 1990
King County SWM GIS Hydrography coverage
King County Wetland Notebooks, 1980
Seattle-Tacoma Airport Final EIS, 2/96

9710DMexluD-1.pdf WG

Figure D-2

DES MOINES CREEK BASIN

Future Land Use/Cover
Scenario without Third Runway



N

0 1/4 1/2 Mile

October 1997

Sources:

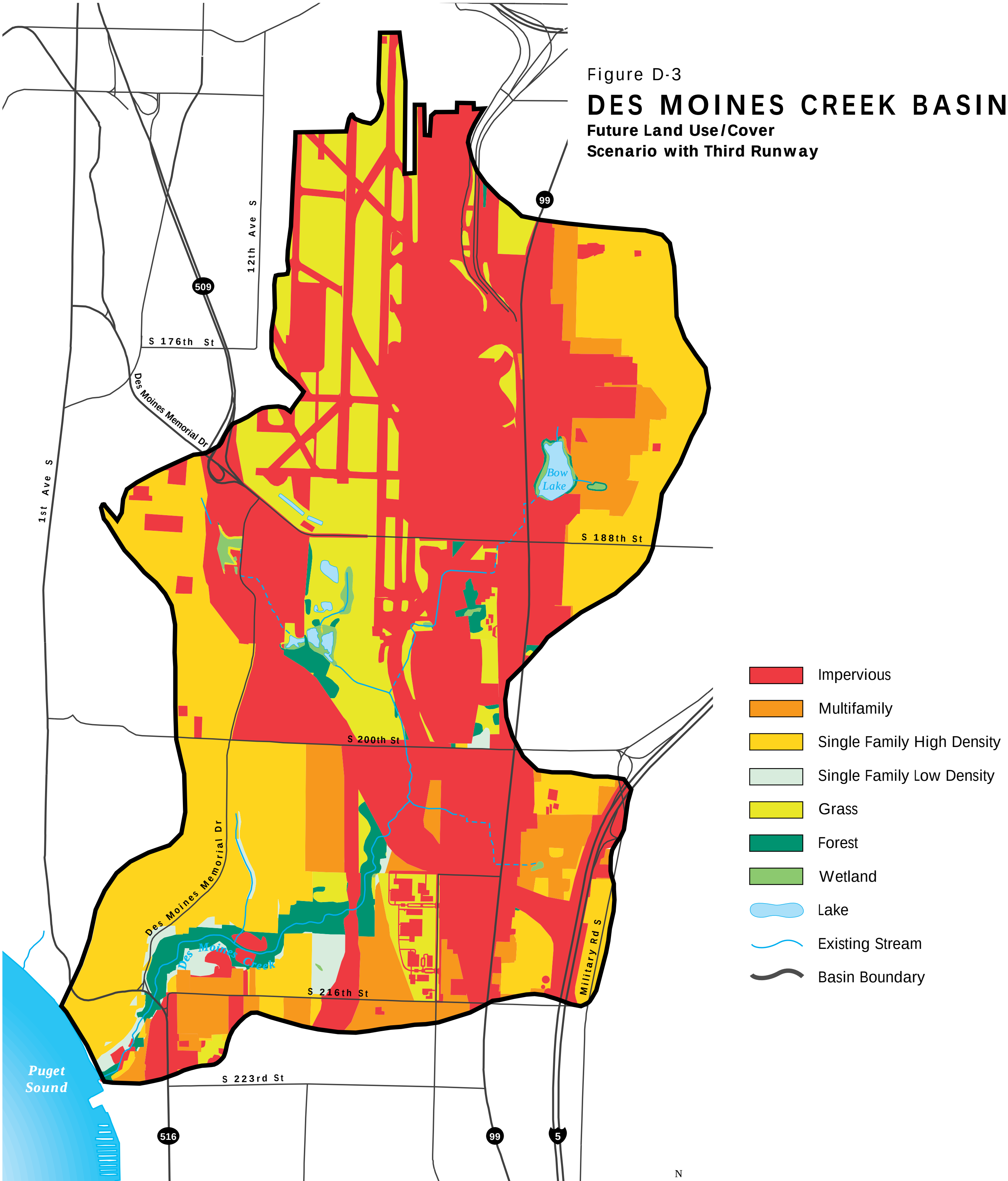
King County SWM GIS Parcels Coverage
King County SWM Existing Land Use Map
King County GIS GMA coverage
King County SWM Basin Reconnaissance Map
King County Sensitive Areas Map Folios, 1980, 1990
King County SWM GIS Hydrography coverage
City of Seatac Comprehensive Plan, 12/95
City of Des Moines Comprehensive Plan and DEIS, 2/95
City of Des Moines Cad Parcel maps
Des Moines Creek Technology Campus DEIS, 2/95
USGS Topography

9710DMfluWOD-2.pdf WG

Figure D-3

DES MOINES CREEK BASIN

Future Land Use/Cover
Scenario with Third Runway



October 1997

Sources:
King County SWM GIS Parcels Coverage
King County SWM Existing Land Use Map
King County GIS GMA coverage
King County SWM Basin Reconnaissance Map
King County Sensitive Areas Map Folios, 1980, 1990
King County SWM GIS Hydrography coverage
City of Seatac Comprehensive Plan, 12/95
City of Des Moines Comprehensive Plan and DEIS, 2/95
City of Des Moines Cad Parcel maps
Seattle-Tacoma Airport Final EIS, 2/96
Port of Seattle South Aviation Support Area FEIS, 3/94
Des Moines Creek Technology Campus DEIS, 2/95
USGS Topography
WSDOT SR-509/South Access Road DEIS, 12/95

9710DMfluWD-3.pdf WG

Wetlands

Wetlands were assumed to exist in the future unless they are located in the SR 509 ROW or on Port of Seattle development or borrow sites, in which case they were assumed to be filled. Likewise, wetland buffers were assumed to exist in the future with the existing land use/cover intact. Wetlands were derived from several sources and conflated based on source map or image quality. Sources included the Sea-Tac Airport DEIS, King County Wetland notebook (1980), and aerial photos.

1. **City of SeaTac**
   Buffer distances were based on the City of SeaTac Comprehensive Plan map #8.1.
2. **Other areas**
   No wetlands were identified in the City of Des Moines, Normandy Park, or unincorporated King County portions of Des Moines Creek Basin.

Landslide Hazard Areas

Landslide Hazard areas were derived from the SWM Division Basin Reconnaissance Final Display Map for Des Moines Creek Basin. Landslide areas are assumed to develop to a 20 percent level of planned use. More intense existing uses/covers were assumed to remain in the future within existing landslide hazard areas.

Stream Buffers

Stream buffers were assumed to remain in existing land use/cover in the future unless covered by SR 509 ROW. Stream locations are based on the SWM Division Geographic Information System (GIS) stream coverage, updated from the Basin Reconnaissance Final Display Map.

1. **City of SeaTac**
   Buffer distances were based on the City of SeaTac Comprehensive Plan map #8.1.
2. **City of Des Moines**
   Buffering is assumed to be implemented by the City of Des Moines based on the Comprehensive Plan, section 4-04-02, with buffer distances comparable to those used by the City of SeaTac and King County. Stream classifications were based on the King County Sensitive Areas map folio.
3. **Other areas**
   No stream buffer areas were identified in Unincorporated King County portions of Des Moines Creek Basin.

Floodplain

The 100-yr floodplain on lower Des Moines Creek is assumed to remain undeveloped in the future. The data source used in mapping floodplains was the Flood Insurance Rate maps dated 5/95.

Steep Slopes

No significant areas of slopes at or greater than 40 percent were identified in the basin, based on USGS topography.

Zoning

Incorporated areas

Zoning was used in the incorporated areas only as a reference to aid land use plan category assignments based on zoning performance standards. Zoning was omitted as a direct map source in order to save production time and because zoning is expected to change to reflect the latest comprehensive plans.

Unincorporated area

Zoning was used in place of land use plan in the small portion of unincorporated King County located in the basin. The two zones in this area, M-P and RS-7200, were assigned the future land use categories Impervious and High Density Single Family, respectively. The data source for zoning was the King County GIS Parcels coverage.

Significant Parcels/Special Cases

State Route 509 and Interstate 5

Right-of-ways were derived from the City of SeaTac Land Use Plan Map, which is overlaid on a parcel base, and from the City of Des Moines digital parcels maps. The right-of-way areas are assigned impervious future land use/cover and take precedence over all sensitive areas.

Sea-Tac International Airport

Two future land use/cover scenarios were produced for Sea-Tac Airport, one assuming the third runway expansion does not occur and the other assuming the third runway expansion does occur. This allowed generation of future scenarios for both assumed conditions. Comparison of the two future scenarios allowed for identification of that portion of the future impacts which could be attributed to the proposed third runway expansion. The following information sources and assumptions were used during development of these two scenarios:

Third Runway Scenario

1) All information pertaining to the development of the third runway is derived from the Final EIS for the Proposed Master Plan Update Development Actions at Sea-Tac International Airport, dated 2/96.
2) The new runway, taxiways, pads, and facilities depicted in this scenario, including the South Aviation Support Area, were taken from EIS exhibit II-7, “Alternative 3, Preferred Alternative”, and were mapped as impervious.
3) Spaces near the airport landing area and not clearly identified as impervious were considered grass land cover in the future.
4) The basin boundary was assumed to not change in spite of the introduction of fill, based on Section IV-10 of the EIS, “Water Quality and Hydrology”. This section implied that future drainage would remain the same as current.
5) No special assumptions applied to borrow areas identified in the EIS other than that pertaining to wetland removal.

6) Wetlands identified as impacted in table IV.11-1 of the EIS were either entirely or partially removed from the future land use/cover map. Within Des Moines Creek Basin, these wetlands include numbers 2, 23, 26, 27, 29, 30, 32, 49, 50, 51, 52, 55, and 53.

No New Runway Scenario

The basic features of Sea-Tac airport remain the same as in existing land use/cover, except that the South Aviation Support Area is assumed built and the Des Moines Creek Technology campus is assumed to proceed.

South Aviation Support Area

The proposed development of the South Aviation Support Area (SASA) was assumed to be independent of the third runway construction. The SASA was mapped in future land use/cover as depicted on Sea-Tac FEIS exhibit II-7, "Alternative 3, Preferred Alternative", and checked against SASA FEIS figure 3.3-3, "Alternative 2" (preferred alternative).

Several features indicated in the SASA FEIS were not depicted on the future land use/cover map because of lack of information: a Potential South Access Freeway, a Potential Arterial, and a Potential Golf Course. These facilities, if constructed, would produce additional impacts due to creation of impervious area. The effect of this new impervious area is not possible to predict given lack of information on the specific location and extent of impervious area created, and the land uses which would be lost in order for these uses to be created.

Des Moines Creek Technology Campus

The data source for this area was the Des Moines Creek Technology Campus DEIS, figure 2-3, "Alternative 2". The figure depicts a conceptual layout of the campus that, while not a preferred alternative, represents the middle option with regard to land use intensity.

APPENDIX E - SHELLFISH MONITORING

Shellfish Sampling at Des Moines Beach Park
King County Surface Water Management
Sampling by Todd Bennett and David Masters
May 6th, 1996

PURPOSE

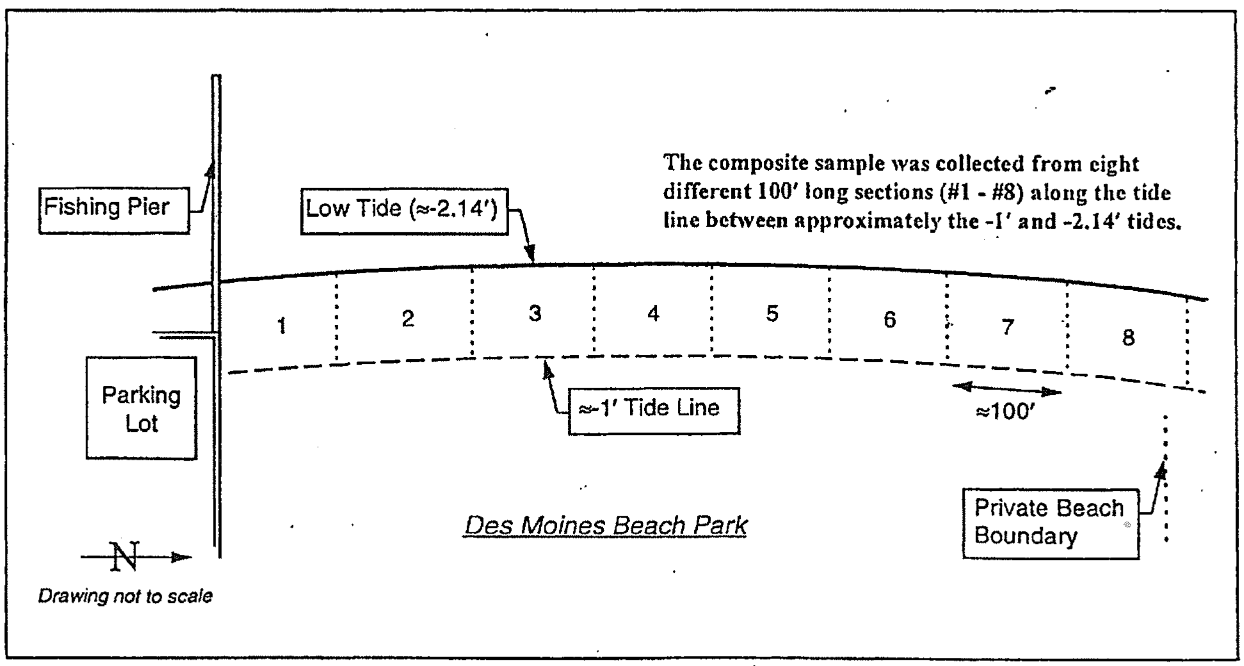
Shellfish sampling was done on May 6th, 1996, at the Des Moines Beach Park. Present were Todd Bennett and David Masters. The purpose of shellfish sampling at the park was to provide a long term bio-indicator for the area and to identify potential health hazards for human consumption.

METHODS

Eight samples were collected from different locations and composited to represent the shellfish community at the beach. These sample locations were selected by marking off 100' intervals along the tide line at approximately a -1' tide (at Seattle). The total length of the line stretched approximately 800' from the 2nd column supporting the landward side of the fishing pier, north to the private beach boundary (see figure 1). Clams were collected from each of these sections between this marked off line and the current tide line. Low tide on the day of sampling was -2.14' (at Seattle).

After digging up the clams, they were sealed in Ziploc bags and iced for transport to METRO labs.

Figure 1. Schematic of Eight Sampling Areas Collected from for the Composite Sample.



When digging we found that the beach was predominately inhabited by butter and horse clams. There were a few cockles. Though we found littleneck shells on the surface we did not find any live littlenecks while sampling.

Butter clams were collected because of their abundance and because they are commonly consumed by humans. The northern most sample area had the greatest number of butter clams. As we moved south, their numbers and size decreased as the abundance of horse clams increased. The size of the butter clams that we collected ranged from 2.2" to 4.2" with most in the upper end of this range. The beach seemed to be devoid of younger and smaller clams, possibly because of the numbers of predators including worms and large populations of Moon Sails.

A second composite sample was to be collected at Marine View Park. The purpose being to have a comparison for the Des Moines Beach Park sample. Horse clams were identified in the area but no butter clams. Because different species do not all feed in the same way, i.e. they filter different particle sizes, it was determined that comparing the two sites would not give us the desired result. No sampling was done at Marine View Park.

RESULTS

Metal levels in the shellfish collected are within the range of other sites around Puget Sound. With the exception of arsenic, metal levels are also below the available guidance levels and screening values.

The results of lab analysis were compared to other studies done around Puget Sound by METRO and the Department of Health (see attached table). Note that because published data on metal levels from strictly butter clams are rare, in some cases, this comparison is based on other species. All the samples from Des Moines Creek are within the range of these samples and are usually located near the middle to low end of the spectrum. Arsenic and copper are the exception to this being near the high end of the range. Although copper levels are relatively high, they are not above screening values.

When compared to FDA guidance levels (*Guidance Document for Arsenic in Shellfish, United States Food and Drug Administration [also separate documents for Cadmium, Chromium, Lead, and Nickel])* and D.O.H. Screening Values *(Puget Sound Ambient Monitoring Program: 1992 and 1993 Shellfish Chemical Contaminant Data Report, May 1996, Washington Department of Health)* Des Moines Creek shellfish metals are typically an order of magnitude lower. FDA lists maximum tolerances in mass/day. To compare this to the metal levels present in the shellfish, a consumption rate of 20g and 80g/person/day was selected based on data published in the FDA and DOH reports. Although arsenic is near the FDA Guidance Level and above the D.O.H. Screening Values these levels of arsenic are commonly found throughout Puget Sound. Also, arsenic in shellfish is typically a less toxic organic form *(D.O.H., 1996, p. 25).*

Des Moines Beach Park Shellfish Sampling Report

PROJECT: 421195CL

Locator KCO
Client Loc: DesMoines Creek
Sampled: May 06, 96
Lab ID: L8459-1
Matrix: SHELLFISH
% Solids:

Parameters	Value	Qual	MDL	RDL	Units	METRO 1994 Data (a) Range (ppm) Min	Max	FDA Guidance (b) Max Tolerance ug/day	Comparable ppm tolerance based on 20g/p/day consumption mg/kg	Comparable ppm tolerance based on 80g/p/day consumption mg/kg	Screening Value (c) mg/kg
	- Wet Weight Basis										
COMBINED LABS											
M.Code=METRO 16-01-003											
Mercury, Total, CVAA	0.007	<RDL	0.0037	0.0149	mg/Kg	0.004	0.01				0.0525
M.Code=METRO 18-04-003											
Antimony, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg	<MDL	0.71				
Arsenic, Total, ICP-MS	3.65		0.02	0.08	mg/Kg	1.3	3.2	130	6.5	1.63	0.263
Barium, Total, ICP-MS	0.054	<RDL	0.02	0.08	mg/Kg						
Beryllium, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg	<MDL	<MDL				
Cadmium, Total, ICP-MS	0.044	<RDL	0.008	0.08	mg/Kg	<MDL	0.21	55	2.75	0.688	0.875
Cobalt, Total, ICP-MS	0.099		0.02	0.08	mg/Kg						
Copper, Total, ICP-MS	3.84		0.02	0.08	mg/Kg	0.893	3.19				35
Lead, Total, ICP-MS	0.115		0.02	0.08	mg/Kg	<MDL	0.99	75	3.75	0.938	
Molybdenum, Total, ICP-MS	0.066	<RDL	0.02	0.08	mg/Kg						
Nickel, Total, ICP-MS	0.425		0.02	0.08	mg/Kg	<MDL	14.5	1200	60	15	
Thallium, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg	<MDL	<MDL				
Zinc, Total, ICP-MS	10.3		0.02	0.08	mg/Kg	10.4	15.7				263
Chromium, Total, ICP	0.23				mg/Kg	0.21	31.3	200	10	2.5	

Parameters	Washington Department of Health [all units ug/g] (c) 1992 Mean	1992 Std	1992 Max	1993 Mean	1993 Std	1993 Max	Other Studies [all units mg/kg] (c) Bellingham Bay Mean	Bellingham Bay Range	Puget Sound Mean	Puget Sound Range	Eagle Harbor Mean	Eagle Harbor Range	McNeil Island Mean	McNeil Island Range	Birch Bay (Reference Area) Mean	Birch Bay (Reference Area) Range	D.O.H. 1986-1987 Data (d) Range
Mercury, Total, CVAA	0.01	0.01	0.06	0.02	0.02	0.08	0.01	<.01 - .02	0.02	<.02 - .03	0.033	.01 - .07	0.011	.01-.11	<.02	<.02	<.02 - .04
Antimony, Total, ICP-MS																	
Arsenic, Total, ICP-MS	1.7	0.34	2.43	2.03	0.51	3.07	1.82	1.1 - 2.1	2.7	1.3 - 4.1	2.9	1.5 - 4.4	1.3	1.1 - 1.4	2.6	2.1 - 3.2	1.6 - 5.2
Barium, Total, ICP-MS																	
Beryllium, Total, ICP-MS																	
Cadmium, Total, ICP-MS	0.2	0.04	0.29	0.25	0.08	0.37	0.21	.18 - .23	0.32	.1 - .54	0.16	.08 - .29	.31	.29 - 0.3	0.3	.22 - .36	.1 - .54
Cobalt, Total, ICP-MS																	
Copper, Total, ICP-MS	1.08	0.35	1.83	1.28	0.52	3.17			1.4	.06 - 2.4					0.98	.06 - 1.6	<.6 - 4.2
Lead, Total, ICP-MS	0.13	0.22	1.03	0.1	0.14	0.65	0.08	.02 - .15	0.09	.04 - .18	0.84	.43 - 2.0			<.04	<.04	<.04 - .42
Molybdenum, Total, ICP-MS																	
Nickel, Total, ICP-MS																	
Thallium, Total, ICP-MS																	
Zinc, Total, ICP-MS	12.4	1.79	16	12.7	2.38	18.3			15	11.7 - 21.2					16.1	14.2 - 18.0	12.2 - 16.4
Chromium, Total, ICP	0.2	0.04	0.29	0.25	0.08	0.37	0.21	.18 - .23	0.32	.10 - .54	0.16	.08 - .29	0.31	.29 - .34	0.3	.22 - .36	.04 - .39

Source: (a) Water Quality Status Report for Marine Waters (King County Area), 1994, King County Dept. of Natural Resources, Water Pollution Control Division (METRO) p. G-7, 8. [Assorted Shellfish Data]
(b) Guidance Document for Arsenic in Shellfish, United States Food and Drug Administration (also separate documents for Cadmium, Chromium, Lead, and Nickel).
(c) Puget Sound Ambient Monitoring Program: 1992 and 1993 Shellfish Chemical Contaminant Data Report, May 1996, Washington Department of Health, p. 15, 19, 26. [Littleneck Data]
(d) *Chemicals and Bacteriological Organisms in Recreational Shellfish, June 1988, Washington Department of Social and Health Services, Shellfish Section,* and E.P.A., p. 33. [Butter Clam Data]

Dovid masters

King County
Water Pollution Control Division
Environmental Laboratory
Department of Natural Resources
322 West Ewing Street
Seattle, WA 98119-1507
(206) 684-2300

June 11, 1996

TO: Michael Grigsby, Surface Water Management

FROM: Mary Silva, Laboratory Project Manager MS
WPCD Environmental Laboratory

SUBJECT: Attached Report for Project 421195CL, Des Moines Creek Clams Samples L8459-1.

Attached is the comprehensive report for the shellfish sample delivered to the laboratory on May 6, 1996. The sample was analyzed in the metals section of the laboratory. A QA/QC data summary is included for your information.

Metals:

The sample was analyzed for arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc. Special precautions were required in preparing this sample. Ordinarily, the sample would be homogenized in a blender with a stainless steel blade. Since stainless steel contains chromium and nickel, and these metals were among the requested analytes, it was necessary to use a titanium blade. Mercury was determined by CVAA. Chromium was to be analyzed by ICPMS, but an interference necessitated the use of ICP. All other metals were determined by ICPMS.

A standard reference material, NIST 1655A (Oyster Tissue), was used as a laboratory control sample. Low recoveries (less than 80%) were observed for chromium and for nickel in this SRM. Historically, the ICP recovery for chromium in this SRM has been widely varied. The sample concentration is near the MDL and this would likely contribute to the variability. There is no historical data for nickel by this method, so the recovery can't be compared to what has previously been found. The digestion method used is considered a "strong" acid digestion but not a "total" digestion. The NIST certification is based on a variety of sample digestion methods, all of which are more vigorous than this.

The data have passed all other internal QA/QC and the data can be used without further qualification.

If you have any questions or need additional information, please call me at 684-2359.

PROJECT: 421195CL

King County Environmental Lab Matrix Report

COMBINED LABS-Solid

Locator	Sample Depth	Lab ID	Arsenic, Total, ICP-MS mg/Kg	Barium, Total, ICP-MS mg/Kg	Cadmium, Total, ICP-MS mg/Kg	Chromium, Total, ICP mg/Kg	Cobalt, Total, ICP-MS mg/Kg	Copper, Total, ICP-MS mg/Kg	Lead, Total, ICP-MS mg/Kg	Mercury, Total, CVAA mg/Kg	Molybdenum, Total, ICP-MS mg/Kg	Nickel, Total, ICP-MS mg/Kg	Zinc, Total, ICP-MS mg/Kg
DesMoines Creek		L8459-1	3.65	0.054	0.044	0.23	0.0985	3.84	0.115	0.0069	0.066	0.425	10.3

King County Environmental Lab Analytical Report

PROJECT: 421195CL

Locator: KCO
Client Loc: DesMoines Creek
Sampled: May 06, 96
Lab ID: L8459-1
Matrix: SHELLFISH
% Solids:

Parameters	Value	Qual	MDL	RDL	Units
		- Wet Weight Basis			
COMBINED LABS					
M.Code=METRO 16-01-003					
Mercury, Total, CVAA	0.0069	<RDL	0.0037	0.0149	mg/Kg
M.Code=METRO 16-02-003					
Chromium, Total, ICP	0.23	<RDL	0.05	0.25	mg/Kg
M.Code=METRO 16-04-003					
Antimony, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg
Arsenic, Total, ICP-MS	3.65		0.02	0.08	mg/Kg
Barium, Total, ICP-MS	0.054	<RDL	0.02	0.08	mg/Kg
Beryllium, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg
Cadmium, Total, ICP-MS	0.044	<RDL	0.008	0.08	mg/Kg
Cobalt, Total, ICP-MS	0.0985		0.02	0.08	mg/Kg
Copper, Total, ICP-MS	3.84		0.02	0.08	mg/Kg
Lead, Total, ICP-MS	0.115		0.02	0.08	mg/Kg
Molybdenum, Total, ICP-MS	0.066	<RDL	0.02	0.08	mg/Kg
Nickel, Total, ICP-MS	0.425		0.02	0.08	mg/Kg
Thallium, Total, ICP-MS		<MDL	0.02	0.08	mg/Kg
Zinc, Total, ICP-MS	10.3		0.02	0.08	mg/Kg

METALS QC SUMMARY FOR KING COUNTY ROADS DES MOINES CREEK CLAM SAMPLE

Element	Method	MDL	Method Blank	Spike Blank Percent Recovery	QC Limit Flag	Sample Value	Duplicate Value	RPD	QC Limit Flag	Matrix Spike Percent Recovery	QC Limit Flag	Lab Control Sample True Value	Lab Control Sample Measured Value	Lab Control Sample Percent Recovery	QC Limit Flag
						L8459-1						NIST 1655A Oyster Tissue			
As	ICPMS	0.02	<MDL	92		3.647	3.588	2		96		14	15.297	109	
Cd	ICPMS	0.008	<MDL	91		0.0440	0.0490	10		93		4.15	3.874	93	
Cr	ICP	0.05	<MDL	90		0.2300	0.2400	1		91		1.441	0.630	44	**
Cu	ICPMS	0.02	<MDL	99		3.8360	3.4810	10		112		66.3	61.869	93	
Ni	ICPMS	0.02	<MDL	96		0.4250	0.4210	1		92		2.25	1.483	66	**
Pb	ICPMS	0.02	<MDL	98		0.115	0.116	1		93		0.371	0.317	85	
Zn	ICPMS	0.02	<MDL	84		10.2900	10.3850	1		108		830	850.395	102	
						L8459-1						NIST 1655A Oyster Tissue			
Hg	CVAA	0.0037	<MDL	106		0.0069	0.0063	9		86		0.0642	0.0659	103	

All results are mg/Kg
MDL=Method Detection Limit.
RPD=Relative Percent Difference.
*RPD exceeds 20%
**Percent recovery out of 80-120% limits.
More numbers than are significant may have been included for calculation purposes.

DESCRIPTION OF COMPREHENSIVE REPORT CONTENTS

Locator

Each sampling site is assigned a unique locator code which defines a unique, specific, geographic reference for that sampling point.

Sample Date

The sample date is labeled Sampled. It is the record of the month, day, and year the sample was collected.

Lab ID

Each sample receives a unique Lab sample number, so that all samples can be referenced by their sample numbers.

Matrix.

Matrix is the Lab's designation of the type of environment from which the sample was taken. There are four groups of matrices: liquids, solids, tissues, and air. The matrices and their codes are as follows.

Liquid

OTHER WTR	LA
INFLUENT	LB
EFFLUENT	LC
DIG SLUDGE	LD
IW WTR	LE
SEWER WTR	LF
STORM WTR	LG
DRINK WTR	LH
GRND WTR	LI
FRESH WTR	LK
SALT WTR	LL
FILTER WTR	LM
BLANK WTR	LN
SEPTAGE	LP
TCLP LEACH	LQ
RECON WTR	LR
SEM EXTRACT	LS

SOLIDS

OTHR SOLID	SA
SOIL	SB
COMPOST	SC
SLUDGE	SD
FRSHWTRSED	SE
SALTWTRSED	SF
IW SLUDGE	SG

Matrices Cont.

IN-LINE SED	SH
SOLIDBLANK	SJ

TISSUES

OTHR TISS	TA
ALGAE	TB
PLANT	TC
SHELLFISH	TD
FISH	TE
CRAYFISH W	TF
CRAYFISH E	TG
ORGANS	TH

AIR

AIR	AB

%Solids

The percent of the non-liquid (by weight) portion of the sample. All data are calculated and stored on a wet weight basis. The % Solid value is used, if requested, to normalize and report data on a dry weight basis. Each sample will be flagged either Wet Weight Basis or Dry Weight Basis in the report. Note that the conversion to a dry weight basis is not applicable to all parameters, for example pH. Also, Particle Size Distribution is not based on moisure content.

Parameters

Parameters (analytes tested for) are reported in sub-groups corresponding to the laboratory that tested for them. The sub-groups are: organics, metals, conventionals, and micro (micro-biology) field analysis, and Aquatic Toxicology.

Qualifiers

Qualifiers give additional information about data points.

<MDL	Less than method detection limit
<RDL	Less than reporting detection limit (practical quantitation limit, PQL)

Some other qualifiers you may find:

Qualifiers Cont.

AD	Adult
B	Blank
C	Confluent growth
CS	Composite sample
D	Dominant
DIL	Diluted
E	Estimated
G	Matrix spike or SRM recovery below acceptance range
H	Sample handling criteria were not met, prior to analysis. Replaced IP and IS qualifiers.
IP	Incorrect preservation Replaced with the H qualifier.
IS	Incorrectly sampled, replaced with the H qualifier.
j#	Chemist's confidence of a Tentatively Identified Compound as indicated by the value of #. The value can vary from 1 to 4, the most confident being 1.
L	Recovery of matrix spike or SRM above acceptance range
LV	Larvae
NF	Not found
P	Present
PU	Pupae
R	Data rejected
S	Sub-dominant
SL	Sample lost
TIA	Text information available
X	Matrix spike or surrogate recovery <10 %
XCM	Exceeds capacity to measure (Instrument X limitation)
XHT	Exceeds holding time
RDL	Equal to the Reporting Detection Limit
>MR,###	exceeds the measurable range ###

Value

The value is the measurement of the parameter expressed in the appropriate units of measure. The units of measure are stated directly beneath the label *Units*.

see reverse side

DESCRIPTION OF COMPREHENSIVE REPORT CONTENTS

Significant Figures

As standard practice the Environmental Laboratory reports values above the RDL to 3 figures. Values below the RDL, or practical quantitation limit, are reported to 2 figures. There are exceptions to the standard convention for micro-biological, aquatic toxicology, field, and some conventional data. In addition, the Laboratory retains data to two more digits than are reported (when available) for calculations such as dry weight or TOC normalization.

Inappropriate Data Combinations

If you are new to the data base, you need to be aware that it is possible to inadvertently commit errors in combining data points. You need to pay attention to the following information to avoid inappropriate combinations: Matrix, Sample Type, and Analytical Method. Also beware that there have been name changes over the years for parameters. Detection limits have changed too. In the early years the detection limit was not always reported with a qualifier. The value you see may be the detection limit rather than a value. If, in older data (i.e. 1970's) you see the lowest value in the series repeated several times, you may need to ask. If you have questions, call Data Management: Kerry Tappel (684-2366) or Tom Georgianna (684-2370).

APPENDIX F - BIBLIOGRAPHY

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