APPENDIX C: BASIN HYDROLOGIC MODEL

C.1 MODEL BACKGROUND

Woodland and Woodard Creek basins were hydrologically modeled using the EPA's Hydrologic Simulation Program-FORTRAN (HSPF). HSPF is a sophisticated computer modeling program which continuously simulates rainfall over a land surface and in-stream hydrologic processes. The model is used to predict continuous stream flows from long-term rainfall records, accounting for changing soil moisture levels over time. This approach offers some distinct advantages over the more traditional models which simulate stream flow for individual storm events. Event-based models cannot accurately predict soil moisture levels at the start of the storm event, nor can they be used to simulate low flows; hence they cannot characterize the overall hydrologic regime of a basin. However, the HSPF model can oversimplify complex groundwater movements, which are common in the basin.

The model used for this basin plan was originally calibrateded by the United State Geological Survey. Aqua-Terra Consultants substantially revised and recalibrated the model to incorporate new data. The Aqua-Terra technical work was summarized in two volumes, *Woodland and Woodard Creek HSPF Calibration for Thurston County, Washington* and *Woodland and Woodard Future Conditions, Thurston County, Washington, Final Results* (Beyerlein and Brascher 1994), which are available from Thurston County. Finally, county staff further revised the Aqua-Terra model to better reflect the existing conditions of a few sub-basins.

The HSPF model requires the division of the surface of each drainage basin into land segments (sub-basins), each with distinctive but reasonably uniform meteorologic, physical (soil, slope, and land cover), and hydrologic traits. It is not necessary for all parcels of each land segment to be contiguous. Therefore, relatively few land segments are needed to represent the complex aerial mosaic of soils, slope, and land cover in each modeled basin.

The HSPF model has the capability of routing stream flow from sub-basins of the surface drainage along connected reaches of a drainage network to the outlet of a drainage basin. Routing allows the simulated runoff from different parts of a drainage basin to be correctly sequenced in time. In order to utilize the routing capability, the linked network of stream channels, drainage pipes, and perennial lakes, ponds, and wetlands that form the drainage of each of the basins was divided into reaches.

Three basic steps were involved in the computer modeling work. First, the model was calibrated against existing stream flow and precipitation data. Second, the model was adjusted to represent past and future land use conditions and run again to simulate past and future stream flows. Third, various proposed control measures (such as regional detention facilities and alternative zoning) were modeled to determine their effects on future flood flows at various points in the basins. Tables C-4 through C-7 summarize the results of the modelled scenarios.

C.2 MODEL CALIBRATION

Rainfall data recorded from October 1988 through September 1990 was used along with recorded stream flow to calibrate the HSPF computer model. Woodland Creek basin contains two continuous recording rain gauges and Woodard Creek basin contains one gauge. The density of rain gauges averaged about 1 gauge per 10 square miles. Pan evaporation data were obtained from the National Weather Service Class A evaporation pan near Puyallup, Washington, for the period March through October 1988.

Stream flow data needed for the calibration was collected at 15-minute intervals from three continuous recording gages in the basins. Woodard Creek has one gage near 36th Ave NE and Woodland Creek has two gages, one at Martin Way near Lacey and one at Pleasant Glade Drive NE. Instantaneous peak flows were estimated a few times each year and stage data were collected by observers periodically. Major storm events and the predicted flow rates were selected from the period October 1988 through September 1990 to calibrate the model and evaluate recommended solutions.
Woodland and Woodard Creek drainage basins were divided into sub-basins according to topographic divides that separate surface runoff. Most of the maps in this plan display the sub-basin boundaries. The Woodland Creek basin was divided into 18 subbasins, and the Woodard Creek basin into 7 subbasins.

Reaches were selected as network components that represent relatively uniform hydraulic characteristics and either drain or connect subbasins. Measurements from field surveys were used to determine general hydraulic characteristics for each reach. Field measurements and maps were used in conjunction with general hydraulic characteristics to determine the storage volumes for the reaches. Reaches may lose water from channel or lake seepage or from multiple outlets, one or more of which discharges out of the basin.

The program recognizes three slope classes: 0 to 3 percent (mild), 3 to 15 percent (moderate), and greater than 15 percent (steep). Land segments for each slope class were identified on U.S. Soil Conservation Service soil survey maps (US Department of Agriculture 1990), and topographic maps were used for verification. Land cover from 1987 aerial photographs were classified into seven land use classes with varying degrees of effective imperviousness. Land cover and soil type were the primary determinants of runoff from each sub-basin.

Effective imperviousness represent the portion of impervious area that rains directly to the channel system. Non-effective impervious surfaces drain to the surrounding soils and were assumed to have the same hydrologic characteristics as the surrounding soils and land cover types. All impervious areas in closed subbasins of the Woodland Creek drainage basin were considered to be non-effective.

Table C-1 HSPF Land Cover Classes and Effective Imperviousness

Land Cover Class	Total Impervious Area (%)	Relative Effective Impervious Area (%)	Total Effective Impervious Area (%)
Low density residential	10	40	4
High density residential	40	65	26
Multifamily	60	80	48
Commercial	90	95	85.5
Forest	0	0	0
Grass	0	0	0
Wetland	0	0	0

The model was calibrated by adjusting the behavior of runoff and soil moisture within each basin, running the recorded rainfall through the model, comparing the results with observed stream flows for the same period, and readjusting the model. The Woodland basin calibration required 58 iterations and the Woodard model required 21 iterations. The final calibrations were judged in three major categories: accuracy of lake level fluctuations; accuracy of annual flow volumes; and, accuracy of individual storm event hydrographs. Table C-2 compares the observed annual flow volumes with the simulated annual flow volumes for the calibrated model.

Ideally, the calibrated model should be verified by running a separate set of recorded data through the model and checking that simulated flows match closely with observed flows; however, separate data for verification was not available. Instead, a formula was developed to correlate measured precipitation levels in the basin with recorded precipitation at the Olympia Airport. This formula was used to convert 35 years of precipitation data from the airport (water years 1956 through 1990) to simulate rainfall for both rain gauges in the basin during the same time period. The simulated streamflow results remained within the expected range during the entire 35-year period. The final two years of the verification run were the same as the initial calibration period. The results of these two runs were compared, and exhibited only minor differences. Table C-3 compares the observed annual flow volumes with the simulated annual flow volumes for the verification run of the model. The deviations between the calibration and verification runs reflect differences between the observed and simulated rainfall records, not changes in the behavior of the model.

Table C-2 Observed vs. Simulated Annual Flow Volumes for Calibrated Model[1]

Woodland Creek at Martin Way				
Water Year	Observed flow (in.)	Simulated flow (in.)	Difference (in.)	Difference (%)
1989	2.08	2.23	+0.15	+7.2
1990	6.72	6.33	-0.39	-5.8
Total	8.80	8.56	-.24	-2.7
Average	4.40	4.28	-0.12	-2.7

Woodland Creek at Pleasant Glade Road				
Water Year	Observed flow (in.)	Simulated flow (in.)	Difference (in.)	Difference (%)
1989	9.21	8.81	-0.40	-4.3
1990	13.11	13.82	+0.71	+5.4
Total	22.32	22.63	+0.31	+1.4
Average	11.16	11.32	+0.16	+1.4

Woodard Creek at 36th Avenue				
Water Year	Observed flow (in.)	Simulated flow (in.)	Difference (in.)	Difference (%)
1989	21.33	20.85	+0.48	+2.3
1990	28.26	27.57	-0.69	-2.4
Total	49.59	48.42	-1.17	-2.4
Average	24.80	24.21	-0.59	-2.4

[1] Calibrated model simulations used precipitation recorded at two rain gauges in the basin to simulate flows.

Table C-3 Observed vs. Simulated Annual Flow Volumes for Verification of Calibrated Model[1]

Woodland Creek at Martin Way				
Water Year	Observed flow (in.)	Simulated flow (in.)	Difference (in.)	Difference (%)
1989	2.08	2.01	-0.07	-3.4
1990	6.72	6.15	-0.57	-8.5
Total	8.80	8.16	-.64	-7.3
Average	4.40	4.08	-0.32	-7.3

Woodland Creek at Pleasant Glade Road				
Water Year	Observed flow (in.)	Simulated flow (in.)	Difference (in.)	Difference (%)
1989	9.21	9.65	+0.44	+4.8
1990	13.11	14.08	+0.97	+7.4
Total	22.32	23.73	+1.41	+6.3
Average	11.16	11.87	+0.17	+6.3

Woodard Creek at 36th Avenue				
Water Year	Observed flow (in.)	Calibrated flow (in.)	Difference (in.)	Difference (%)
1989	21.33	21.70	+0.37	+1.7
1990	28.26	26.30	-1.96	-6.9
Total	49.59	48.00	-1.59	-3.2
Average	24.80	24.00	-0.80	-3.2

[1] Verification of the calibrated model used a synthetic 35-year precipitation record for the basin, correlated with Olympia Airport precipitation data, to simulate flows.

C.3 MODELING OF PAST AND FUTURE CONDITIONS

Past or "Forested" Conditions The calibrated model was adjusted to reflect the natural conditions in the basin prior to development, in order to understand the current extent of hydrologic impacts to the stream systems. The land cover types for all of the developed lands were changed to forest, grass or wetland cover according to the native vegetation for each soil type as reported by the U.S. Soil Conservation Service (U.S. Department of Agriculture 1990).

The predictions for the forested condition indicate the relative impacts of development. However, they do not reliably simulate actual pre-development conditions because they assume the streams and tributary areas existed in their current location and configuration, but historic surveys indicate that the actual streams have been extensively ditched, filled, and rerouted so that their natural contributing drainage area boundaries were substantial different from today's basin boundaries.

Future "Build-Out" Conditions The calibrated model was adjusted to reflect future conditions when all developable lands have been developed according to existing zoning laws, in order to predict the extent of the hydrologic impacts from future development. The future conditions model made the following assumptions:

1) Twenty percent of all forested and pasture land outside the Urban Growth Management Area (UGMA) will be left undisturbed.
2) All the remaining undeveloped land (excluding wetlands) will be developed to the maximum density allowed by law.
3) Low-density development within mostly undeveloped sub-basins will be converted to the highest density allowable by law. Developments within highly developed sub-basins that are not likely to change will not be converted.
4) The current and future land cover categories have the same effective impervious area characteristics (described in Table C-1).
5) Runoff and stream flow routing will not change (current law severely restricts stream or runoff relocations).
6) The infiltration capacity of existing drainage conveyance systems will not change.
7) All new developments will meet the requirements of the 1994 county drainage design standards. Therefore, all new development on outwash soils will infiltrate 100% of the runoff, and only new developments on till soils will create new runoff.
8) Wetlands will not be developed.

C.4 MODELING OF FUTURE MANAGEMENT MEASURES

The model was altered in several ways to predict the hydrologic impact of various potential stormwater management meaures. The effects of one several management measures were modelled and ineffective measures were discarded. The effective measures were grouped into three service levels, then further consolidated into two service levels to represent alternatives for reducing future impacts.

Service Level 1 The goal of service level 1 was to prevent increases in peak stream flows in the future. The effect of current drainage design standards proved to be insufficient for preventing future flow increases. The model analyzed the effects several regional stormwater detention facilities on future flows. Chapter 7, recommendations WL26A-G and WD12A-B describe the projects that best simulated the service level 1 goal.

Service Level 2 The goal of service level 2 was to decrease future peak flows to below exisitng peak flows. This requires additional measures beyond the projects modelled in service level 1. Regional detention structures proved insufficient to reduce future peak flows to below current levels, so additional measures to prevent future impacts were developed, including higher drainage design standards and more restrictive cluster zoning requirements. Chapter 8, recommendations WL26I-J and WD12D-E describe the measures required to reduce future peak flows to attain service level 2 goals. The cluster zoning measure was modelled by increasing the undeveloped lands outside the UGMA from 20% to 70%. This measure had the largest impact on the mouths of both creeks, which are located outside the UGMA boundary.

Table C-4 Predicted Woodland Creek 2-Year Flood Flows

Location	Sub-basin	Forested Condition	Existing Condition	Future Condition	Service Level 1	Service Level 2
Hicks Lake outlet	WL4	3	4	5	5	5
Pattison Lake outlet	WL5	16	22	24	24	24
Long Lake outlet	WL6	6	17	19	17	16
Subbasin 8 trib	WL8	0	8	8	8	8
Lake Lois Outlet	WL8	1	8	10	10	8
Wdln Cr @ Martin Wy	WL12A	8	28	32	30	30
Lower College Creek	WL15	4	22	33	12	11
Middle College Creek	WL15A	5	31	42	14	14
Upper College Creek	WL15B	2	12	16	8	8
Thompson Place trib	WL17	8	55	63	63	62
Wdln Cr @ Draham	WL17	21	97	115	97	93
Eagle Creek	WL21	16	23	53	36	21
Palm Creek	WL22	3	6	9	4	4
Fox Creek	WL23	11	16	27	11	10
Wdln @ Pleasant Gl	WL22	53	141	199	141	123
Jorgensen Creek	WL25	6	9	14	7	5
Mouth	WL27	82	189	260	200	174

Table C-5 Predicted Woodland Creek 100-Year Flood Flows

Location	Sub-basin	Forested Condition	Existing Condition	Future Condition	Service Level 1	Service Level 2
Hicks Lake outlet	WL4	10	10	11	11	11
Pattison Lake outlet	WL5	30	41	44	44	43
Long Lake outlet	WL6	27	43	49	38	36
Subbasin 8 trib	WL8	0	23	24	24	24
Lake Lois Outlet	WL8	16	36	40	40	32
Wdln Cr @ Martin Wy	WL12A	39	69	76	71	70
Lower College Creek	WL15	12	52	107	27	22
Middle College Creek	WL15A	15	61	95	25	23
Upper College Creek	WL15B	4	30	43	15	15
Thompson Place trib	WL17	23	87	128	128	91
Wdln Cr @ Draham	WL17	66	187	283	213	180
Eagle Creek	WL21	44	63	187	95	80
Palm Creek	WL22	9	17	32	6	6
Fox Creek	WL23	35	47	47	15	15
Wdln @ Pleasant Gl	WL22	139	306	538	315	260
Jorgensen Creek	WL25	19	27	54	12	12
Mouth	WL27	227	455	682	469	393

Table C-6 Predicted Woodard Creek 2-Year Stream flows

Location	Sub-basin	Forested Condition	Existing Condition	Future Condition	Service Level 1	Service Level 2
Fones Road trib	WD1	1	35	37	37	37
Taylor wetland outlet	WD2	2	32	33	9	9
Ensign Road	WD3	4	30	30	20	8
South Bay Road	WD4	11	32	41	35	28
36th Avenue	WD5	22	42	55	48	40
Libby Creek	WD6	2	4	5	5	4
Mouth	WD6	45	72	98	93	77

Table C-7 Predicted Woodard Creek 100-Year Stream flows

Location	Sub-basin	Forested Condition	Existing Condition	Future Condition	Service Level 1	Service Level 2
Fones Road trib	WD1	2	62	64	64	64
Taylor wetland outlet	WD2	4	24	60	10	10
Ensign Road	WD3	9	35	49	30	11
South Bay Road	WD4	27	51	58	51	42
36th Avenue	WD5	58	76	89	80	70
Libby Creek	WD6	8	10	13	13	11
Mouth	WD6	132	149	185	177	152

Figure C-1 Woodland Creek at Martin Way Calibration Hydrograph: Simulated vs. Observed Flow

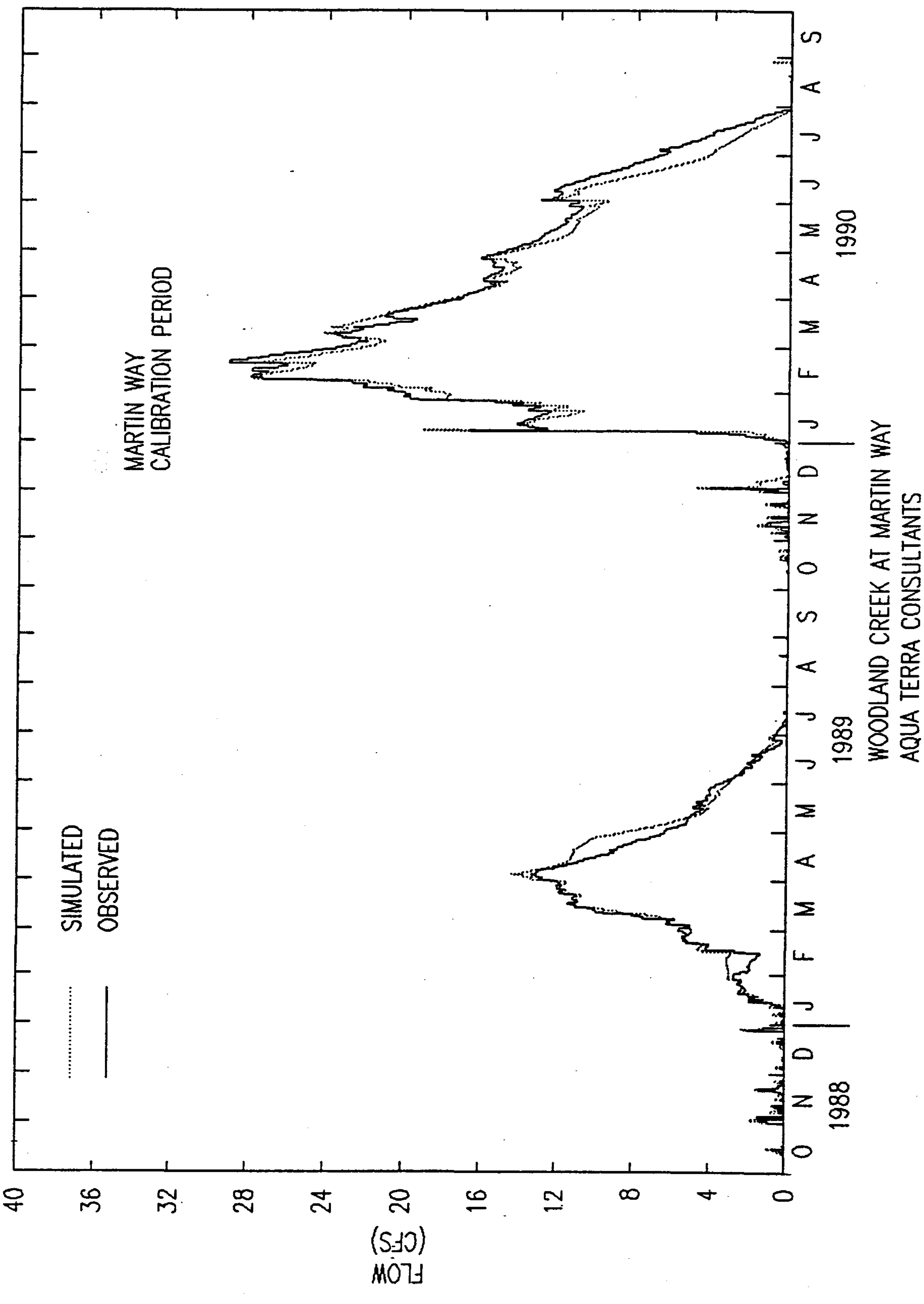


Figure C-2 Woodland Creek at Pleasant Glade Road Calibration Hydrograph: Simulated vs. Observed Flow

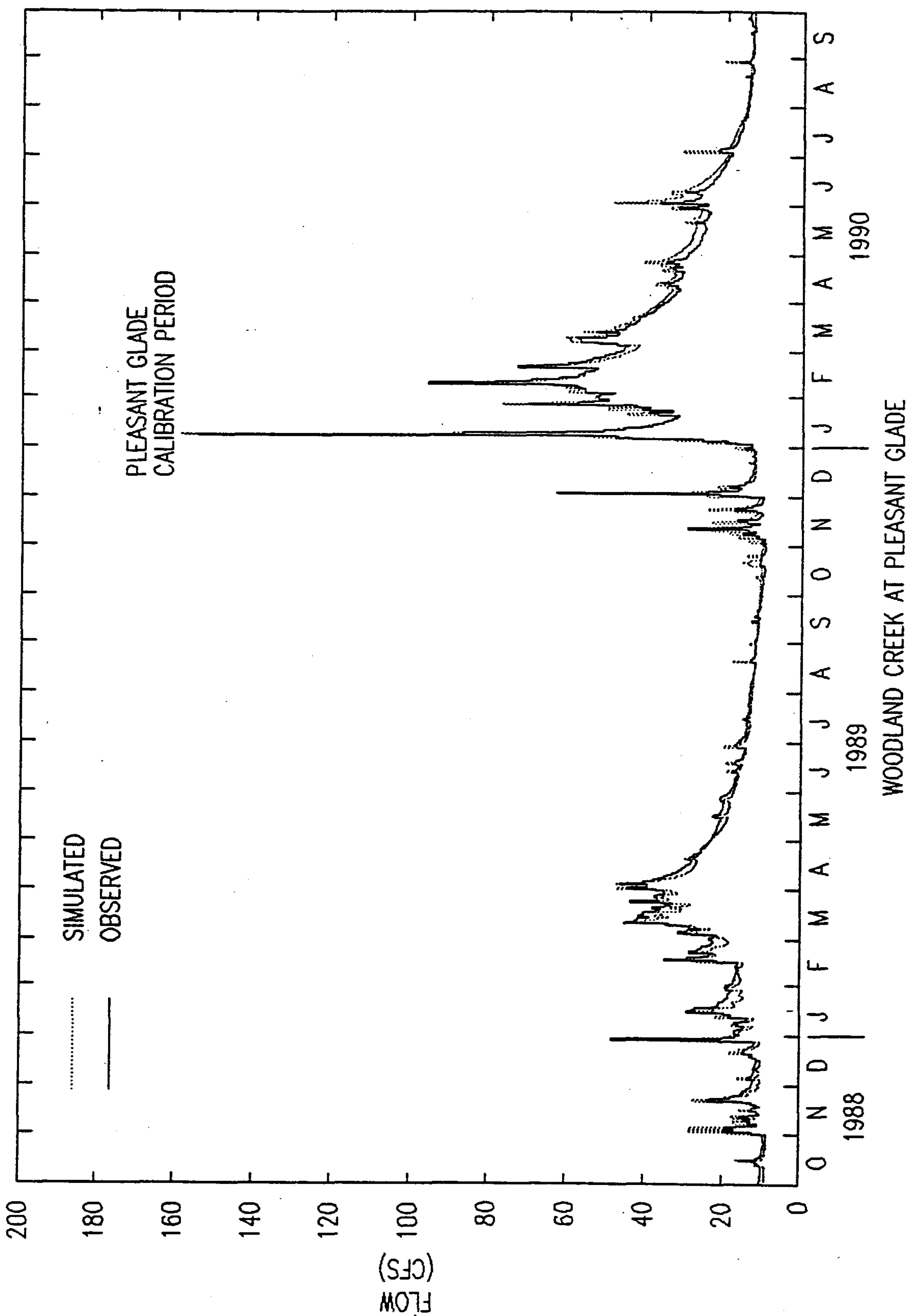
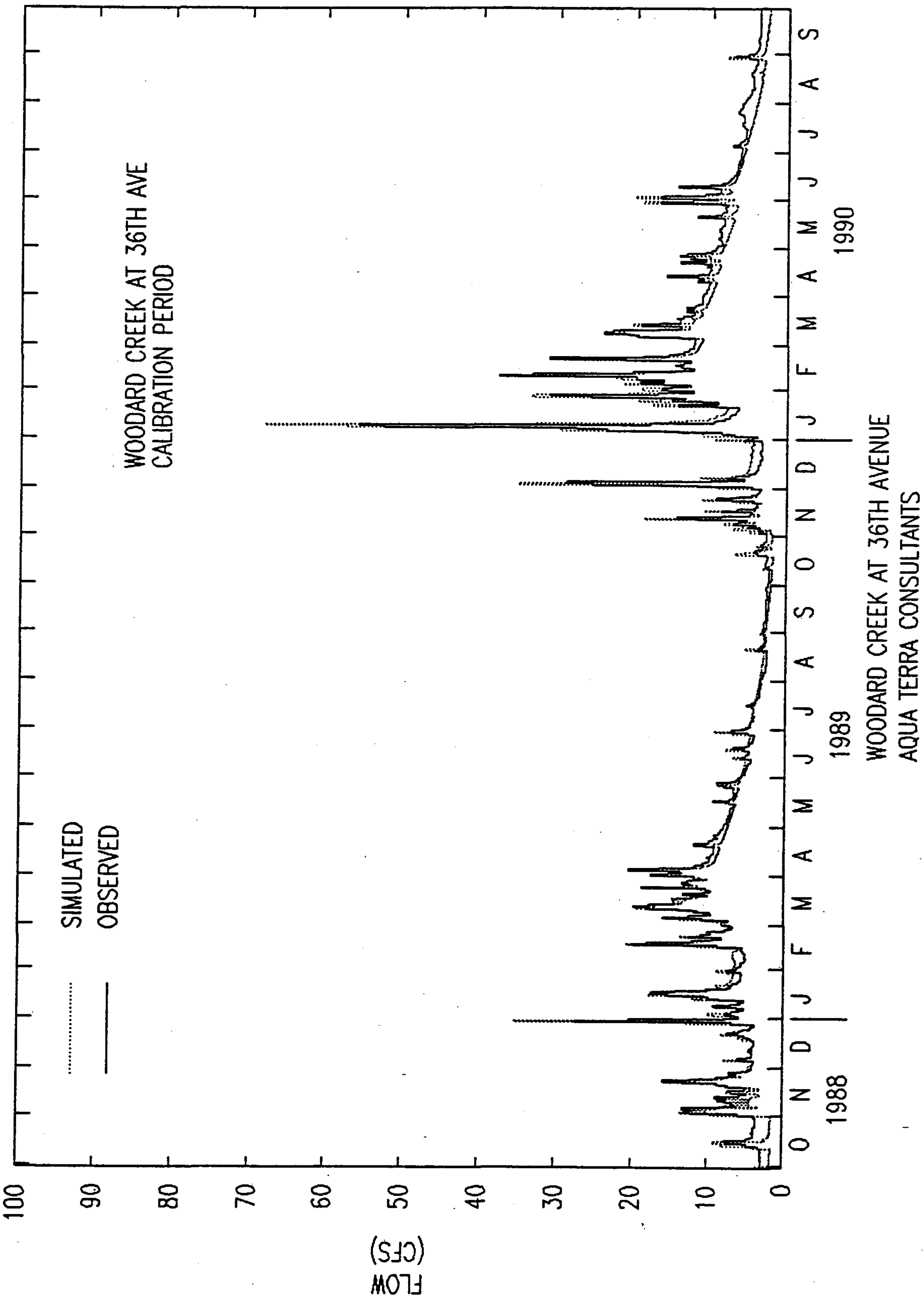


Figure C-3 Woodard Creek at 36th Avenue NE Calibration Hydrograph: Simulated vs. Observed Flow



APPENDIX D: WILDLIFE SPECIES OF WOODLAND BASIN

WILDLIFE INVENTORY FROM *WOODLAND CREEK, A BASELINE STUDY* (DOBBS 1977)

Birds:

red-winged blackbird
ring-necked pheasant
blue grouse
ruffed grouse
California quail
rufous hummingbird
belted kingfisher
downy woodpecker
Vaux's swift
red-shafted flicker
Steller's jay
common crow
western flycatcher
olive-sided flycatcher
common bushtit
chestnut-backed chickadee
black-capped chickadee
red-breasted nuthatch
brown creeper
winter wren
Bewick's wren
American robin
varied thrush
Oregon junco
cedar waxwing
purple finch
spotted towhee
golden-crowned sparrow
fox sparrow
song sparrow
evening grosbeak
Cooper's hawk
red-tailed hawk
sharp-shinned hawk
northern harrier
American kestrel
osprey
gyrfalcon
screech owl
great horned owl
bald eagle
great blue heron
western grebe
mallard

Mammals:

black-tailed deer
red fox
raccoon
river otter
mink
opossum
spotted skunk
weasel
snowshoe hare
gray squirrel
Townsend's chipmunk
muskrat
bushytailed woodrat
white-footed mouse
northern water shrew
Trowbridge's shrew
Pacific shrew
Townsend's mole
dusky shrew
big brown bat
silver haired bat
hoary bat

Reptiles and Amphibians:

western fence lizard
northern alligator lizard
common garter snake
western garter snake
Pacific giant salamander
Olympic salamander
rough-skinned newt
Pacific tree frog
western toad

APPENDIX E: GEOLOGIC GLACIAL SEDIMENTS

Following is a description of the different geological formations present in the basins. The sequence begins at the lowest level, and moves up through the different deposits to the surface.

1. **Volcanic Bedrock** underlies most of the region's glacial deposits. The upper part of the bedrock is intensively weathered which has resulted in the formation of soils.

2. **Pre-Salmon Springs** deposits are primarily fine-grained sands and gravels which constitute a silt-clay. The clay is known to many people as "blue-clay." The clay has very poor water percolation. However, there are many sand and gravel deposits that are important aquifers. In the peninsula area, deposits of sand and gravel extend as far down as 1,000 feet below sea level.

3. The **Salmon Springs Drift** is composed of stratified sand and gravel that has low permeability. On the peninsulas, the base of the Drift usually begins near sea level. Its stratification sequences are most often thirty feet thick, but are ninety feet thick in some places. It underlies most of the upland watershed region and is an important aquifer which is the source of groundwater for deep wells. The wells usually encounter the water table within a few tens of feet above sea level.

4. **Kitsap Formation** deposits are generally less than fifty feet thick and consist of clay, silty clay, silt, some sand, and some layers of gravel near its base. The Kitsap Formation is not permeable and is not a good aquifer. It is however, the foundation for the aquifers above it that are found in the Colvos Sand. It effectively retards the downward percolation of water, thus enabling the aquifers in the Colvos Sand to exist.

5. **Colvos Sand and Vashon Advance Outwash** are sands and gravels deposited by the advancing Vashon glacier. They are an average thickness of thirty feet but can be as thick as eighty feet. The Colvos Sand and advance outwash are often blended together. They are of moderate permeability and provide domestic water supplies throughout much of the northern prairie area.

6. **Vashon Till** is referred to as "hardpan." It is an unsorted deposit of gravel that is held together by sandy silt and clay. Its composition is concrete-like by sandy places. Till covered areas are usually poorly drained and covered by vegetation. When below the surface, till creates aquifers that are found in the layers of looser sand and gravel above it.

7. **Vashon Recessional Outwash** (gravel). During the recession of the Vashon glacier, meltwater streams deposited tremendous quantities of gravel and sand. The size of the gravel ranges from small boulders to small granules. Outwash generally rests on

till, and generally provide excellent water percolation. The hard till underneath creates small aquifers, particularly in the highland areas of the watershed. The water accumulates on top of and within the till. The aquifers supply enough water for domestic use, usually from small wells located 100-160 feet above sea level.

8. **Recent Alluvium** deposits are silts and sands and some gravel deposited after the complete recession of the Vashon ice sheet. In most places, the alluvium is a shallow valley fill covering the underlying deposits. Large ground water supplies can be developed from alluvium deposits.