WRIA 1 Watershed Management Project
Phase III, Task 4.2 report

Validation of Surface Water Quantity Model through Analyses of Scenarios

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December 2007

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Abstract

This report presents a validation of the surface water quantity model developed as part of the Water Resources Inventory Area (WRIA) 1 Watershed Management project. An enhanced version of the TOPNET rainfall runoff model was applied to the WRIA 1 study area. TOPNET is a distributed hydrologic model with basic model elements being topographically delineated drainages that discharge into the stream network that is then used to route flow to the outlet. The enhanced TOPNET includes additional processes such as irrigation, artificial drainage and integrated water management of user demands, return flows, diversions and storage. Three input scenarios are used to validate the model. These scenarios are (1) Historic, representing pre-settlement conditions, (2) Existing conditions, and (3) Full Buildout conditions, representing a plausible scenario for additional development in the future. The scenarios were specified in terms of land use and land cover as well as population increases. User demands on water were simulated based in this input. Output from the model simulations of these scenarios was analyzed to demonstrate the functionality of the model and illustrate the potential impact on the hydrology from these scenarios. The simulations show that overall, at the scale of the Nooksack River basin, impacts of changes on the quantity of water are minimal, but that within the area at the smaller scale of drainages, there are locations with increased water use and land use land cover changes; and that there can be significant impacts on the hydrology, with runoff becoming more flashy and increasing due to impervious areas and reduced evapotranspiration, but with streamflow at other times or places being reduced due to user withdrawals.

Introduction

The purpose of this project was to develop a model that could assist the watershed planning process in Water Resources Inventory Area (WRIA) 1 in the State of Washington. This project was completed in three phases:

1. Phase I, Work plan development
2. Phase II, Preliminary data collection
3. Phase III, Technical studies involving model and decision support system development

The surface water quantity component of phase III comprised two tasks:

1. Task 4.1: Develop and Implement Surface Water Quantity Model Components and Integrate into the DSS
2. Task 4.2: Validation of Model through Analyses of Scenarios

This is the final report on the development and calibration of the surface water quantity model developed under task 4.2. A separate report describes the surface water quality model work of task 4.1. The Task 4.1 report should be read before this report to understand the model that is being used here.

This report describes the application of the WRIA 1 Surface Water Quantity Model for three management scenarios of interest. This application serves to validate and illustrate the capability of the model for the simulation of water quantity implications of different management scenarios. The three scenarios considered are:

- Historic
- Existing
- Full Buildout

The Historic conditions scenario is intended to represent the watershed in a natural pre-settlement condition and does not include any human related land use nor management. The Existing conditions scenario is intended to represent present conditions and include current land cover and water use derived from present population estimates and present water management infrastructure. The Full Buildout scenario is intended to represent build out at current zoning and population projections for 2022 as described in the Whatcom County Comprehensive plan. Within the Existing conditions scenario there are actually two subscenario's. One is existing conditions as is. The second is existing conditions without water management, designated "Existing NWM". This is not a realistic alternative for water management because it is implausible for the watershed to be managed without any water use. It is, however, used here for validation of the model to examine and illustrate how the water management parts of the model work. By comparing results with and without management we can see the effect of individual management options such as the Middle Fork Diversion, withdrawals from Lake Whatcom and pumping from groundwater. There are, therefore, effectively four scenarios that are analyzed in this report:

- Historic
- Existing

- Existing no water management
- Full Buildout.

The surface water quantity model (TOPNET) for WRIA 1 has three input categories for water management.

0. No Water Management
1. Water Rights Allocation
2. Water Demand Allocation

Within category 0, "no water management" the simulation of water management is bypassed. In category 1, "Water Rights allocation" each user source is associated with a water right that specifies the allowable quantity and priority date. Withdrawal requests to these sources, up to the allowable quantity, are processed in priority date order to ensure that higher priority sources get allocated water first. In category 2, "Demand allocation" each user, either irrigation or non-irrigation, generates a demand based on simulated conditions, such as soil moisture, in the case of irrigation users, or population and time of year in the case of urban users. The Historic and Existing NWM scenarios were processed with water management category 0, "No Water Management". The Existing and Full Buildout scenarios were processes with water management category 2, "Water Demand Allocation". We do not present any results from the model run under management category 1, "Water Rights Allocation".

Definition of Scenarios

The three primary scenarios are defined in terms of land use and land cover (LULC) and population. This information together is used to define water users and their associated water demand. LULC also directly affects some of the hydrologic processes that were simulated. Table 1 summarizes the LULC classes over WRIA 1 for each of the scenarios. Figure 1 gives maps of LULC for each Scenario. The Existing conditions LULC was derived from the National Land Cover Dataset (NLCD) downloaded September 2003 and described in the prior USU Report "Mapping Methodology and Data Sources for Existing Conditions Landuse/Landcover within Water Resource Inventory Area 1 (WRIA 1) Washington, U.S.A.". Historic conditions LULC was derived from the Existing conditions LULC referring to the work of Collins and Sheikh (2004) and formatted by the USU team as described in the prior USU Report "Mapping Methodology and Data Sources for Historic Conditions Landuse/Landcover within Water Resource Inventory Area 1 (WRIA 1) Washington, U.S.A.". Full Buildout LULC was derived as described in the prior USU Report "Mapping Methodology and Data Sources for Full Buildout Conditions Landuse/Landcover within Water Resource Inventory Area 1 (WRIA 1) Washington, U.S.A.". Population density by drainage is given in Figure 2 for the Existing and Full Buildout scenarios. Population data was obtained from ECONorthWest and is included in a spreadsheet (population_data.xls) in the electronic appendix.

Management and user inputs for the Existing and Full Buildout scenarios were derived entirely from the table of population projections per drainage and from LULC layers following the procedures described in the accompanying report "Surface Water Quantity Model Development and Calibration". Per person water use rates were held constant (100 gal/day) over the residential LULC classes. The areas of these LULC classes and population in each drainage were used to calculate a population density used to generate water demand. Changes in LULC and changes in population resulted in changed residential water demand that was represented in the user.txt input file to the model. The areas served by public water supply systems were kept the same across scenarios, so the demand on these public water supply systems only changed due to changes in population and land use within these service areas. Commercial, Industrial, and Transportation class LULC water demand is generated on a per unit area basis. The per acre use rate (3540 gal/acre/day, based on USGS Water use estimates for 2000) was held constant for both Existing and Full Buildout scenarios. Changes in LULC led to corresponding changes in demand. Irrigation demand in the surface water quantity model is driven by the irrigated area. Table 2 gives the fraction of LULC classes presumed to be irrigated for the purposes of deriving irrigation demand.

Table 1. Land Use Land Cover Classes for WRIA 1 modeling scenarios

Code	Description	Historic		Existing		Full Buildout	
		Area (km^2)	% of Total	Area (km^2)	% of Total	Area (km^2)	% of Total
11	Water	133.3	3.67	52.1	1.43	51.2	1.41
12	Ice/Snow	82.8	2.28	82.2	2.26	82.3	2.26
21	Low Intensity Residential			139.3	3.83	254.3	7.00
22	High Intensity Residential			1.5	0.04	34.4	0.95
23	Commercial/ Industrial/ Transport			44.3	1.22	161.0	4.43
31	Bare Rock/ Sand/ Clay	144.1	3.96	138.6	3.81	135.8	3.73
32	Quarries/ Strip Mines/ Gravel Pits			5.4	0.15	5.3	0.15
33	Transitional			108.6	2.99	106.3	2.92
41	Deciduous Forest	51.9	1.43	167.5	4.61	62.3	1.71
42	Evergreen Forest	2811.4	77.3	944.9	26.0	892.3	24.5
43	Mixed Forest	29.9	0.82	1118.2	30.8	914.0	25.1
51	Shrubland	67.4	1.86	99.9	2.75	87.1	2.40
61	Orchards/ Vineyards/ Other			10.5	0.29	8.9	0.24
71	Grassland	58.8	1.62	74.7	2.06	69.7	1.92
81	Pasture/ Hay			414.2	11.4	564.3	15.5
82	Row Crops			53.6	1.47	45.1	1.24
83	Small Grains			16.4	0.45	13.2	0.36
84	Fallow			0.099	0.003	0.081	0.002
85	Urban/ Recreational Grass			3.6	0.10	20.5	0.56
89	Dairy			147.2	4.05	115.3	3.17
91	Woody Wetlands	238.4	6.56	9.8	0.27	9.5	0.26
92	Emergent Herbacious Wetlands	17.1	0.47	2.3	0.062	2.2	0.061
	Total	3635.0	100	3635.0	100	3635.0	100

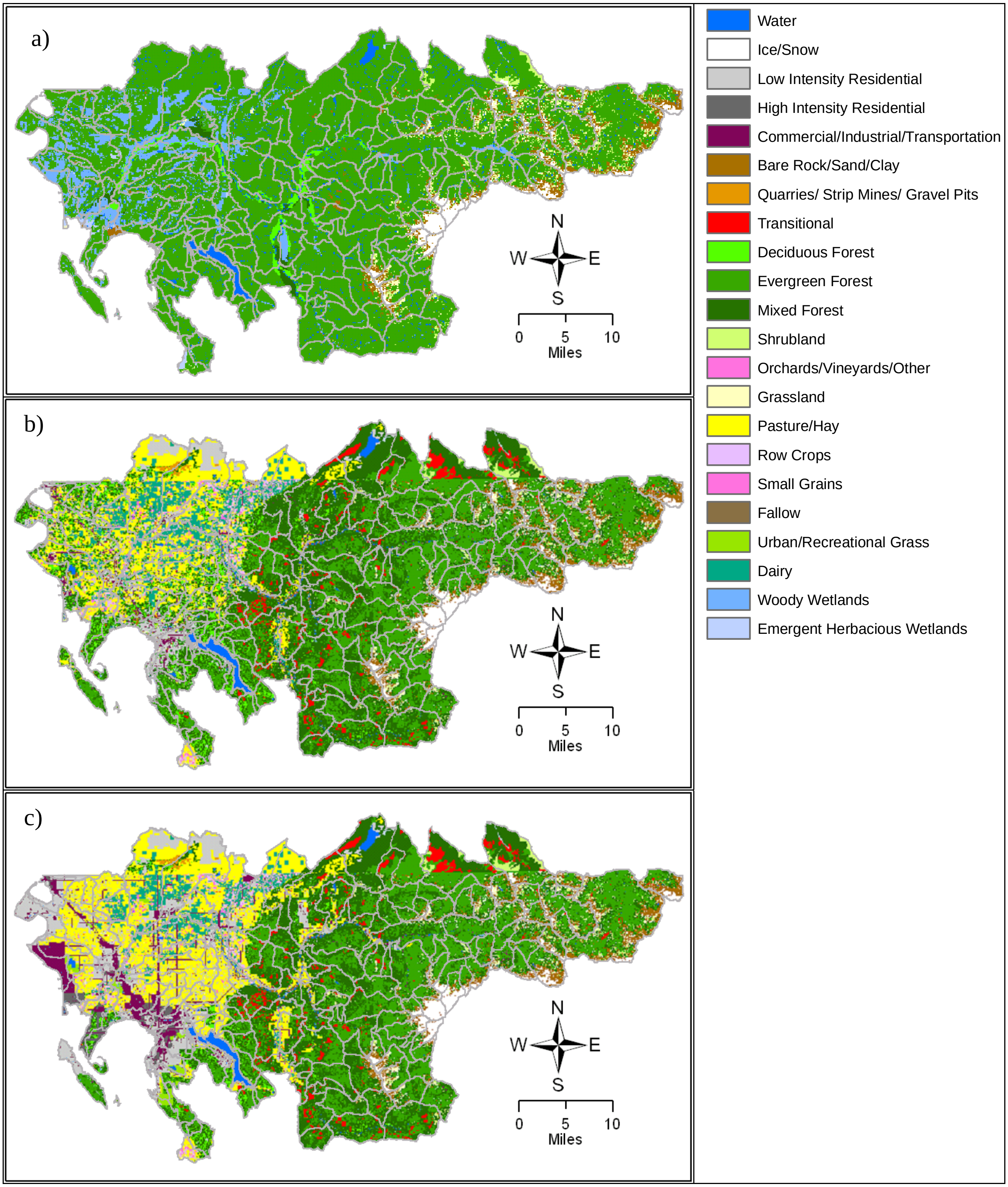


Figure 1. WRIA 1 Land Use Land Cover maps. a) Historic conditions, b) Existing Conditions, c) Full Buildout conditions

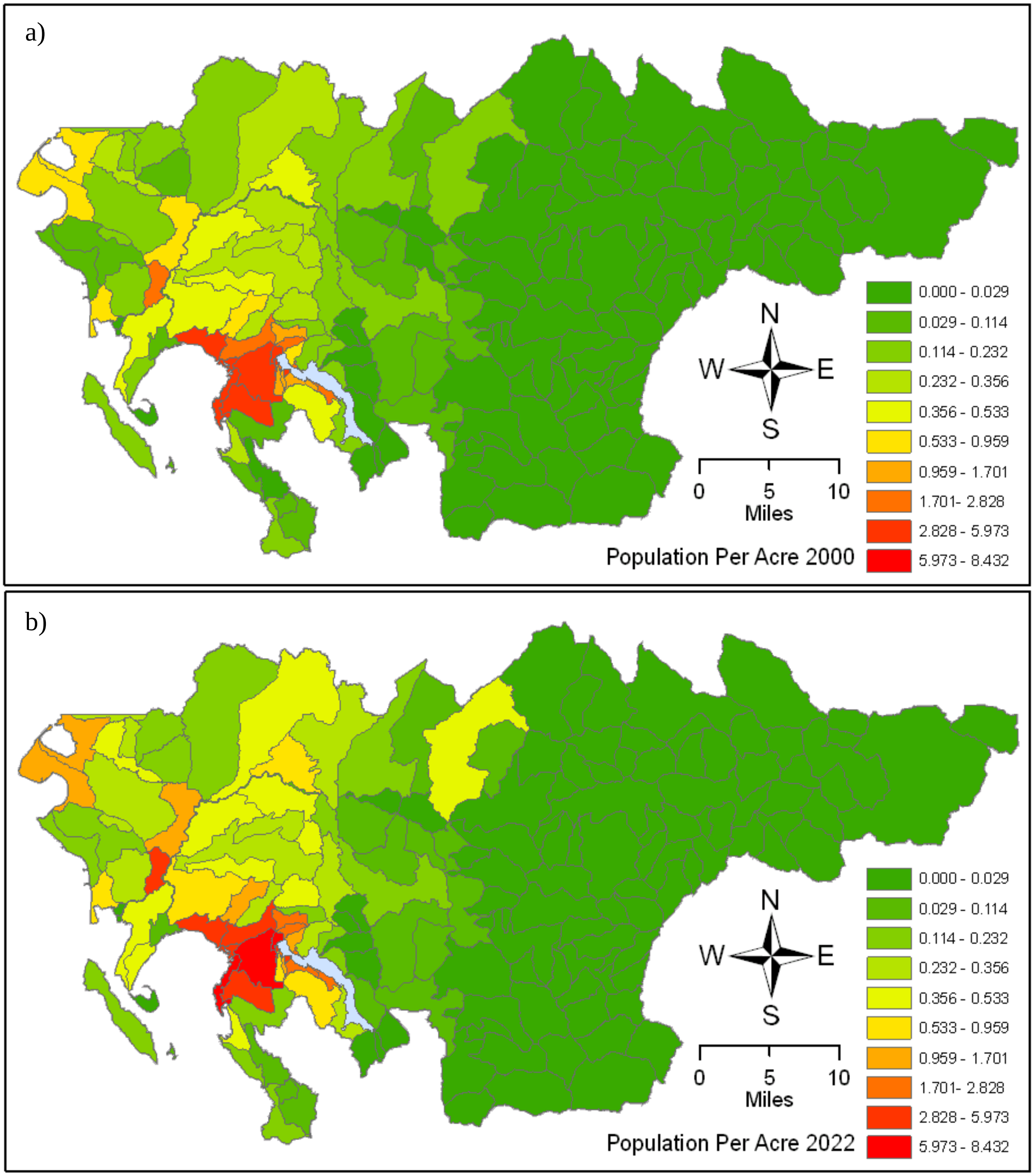


Figure 2. WRIA 1 Population density. a) Existing Conditions, b) Full Buildout conditions

As described in the accompanying report "Surface Water Quantity Model Development and Calibration", an irrigation user was created for each drainage with positive irrigation fraction with source location specified as 70% groundwater and 30% surface water. Irrigation demand was driven by the model simulations of soil moisture over the irrigated fraction of the drainage.

Table 2. Land Use Land Cover Class presumed to be irrigated

LULC Class	Irrigated Fraction
Class 61 - Orchards/Vineyards/Other	0.5
Class 81 - Pasture/Hay	0.5
Class 82 - Row Crops	0.5
Class 83 - Small Grains	0.5
Class 85 - Urban/Recreational Grasses	0.8
Class 89 - Dairy Farms	0.5

Artificial drainage through ditch and tile drains is a significant anthropogenic impact on the hydrology of WRIA 1. Figure 3 shows the areas of WRIA 1 subject to artificial drainage based on shapefiles provided by NRCS Lynden Field Office Resource Conservationist John Gillies.

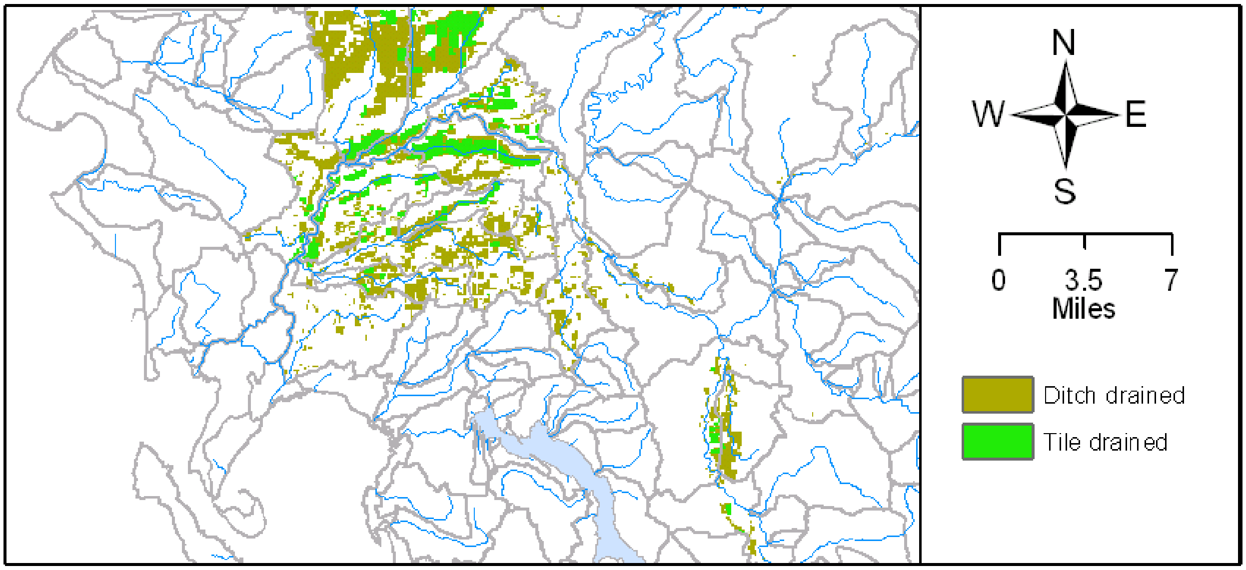


Figure 3. WRIA 1 area subject to artificial drainage

Artificial drainage in the model is implemented as part of the rainfall-runoff transformation, and as such it is not controlled by the water management input category. For the Historic conditions scenario, the degree drained input in setting up the drainage parameters was set to 0, resulting in no artificial drainage. For both Existing condition scenarios, and for the Full Buildout scenario the degree of artificial drainage in each drainage model element was calculated based on the area in each of these artificial drainage classes in each drainage model element. Therefore, all three of these (Existing, Existing NWM, and Full Buildout) scenarios have simulated artificial drainage. The no water management option for Existing NWM does not simulate without artificial drainage.

Analysis of Scenarios and Model Sensitivity

The simulation period for this work was chosen to be the period from 1961-2005. This climatology was chosen to be sufficiently long and representative of both phases of Pacific inter-decadal climate oscillation (PDO), and to provide meaningful evaluation between management alternatives that included both wet and dry periods. For these scenario runs, the model was initialized on 10/1/1959 and run until 12/31/2005. Analysis of the data started on 10/1/1960, which is the beginning of the 1961 water year, allowing a one year spin-up period for the internal state of the model to adjust to the climate inputs and forget the initial conditions.

Comparison of Historic to Existing NWM

Figure 4 presents a map depicting the difference in mean streamflow over the 55 year simulation period (1961-2005) between the Historic and Existing NWM simulations. This is presented to analyze the overall sensitivity to the difference in LULC and impact of artificial drainage on the hydrology going from Historic conditions to present, notwithstanding any direct water use.

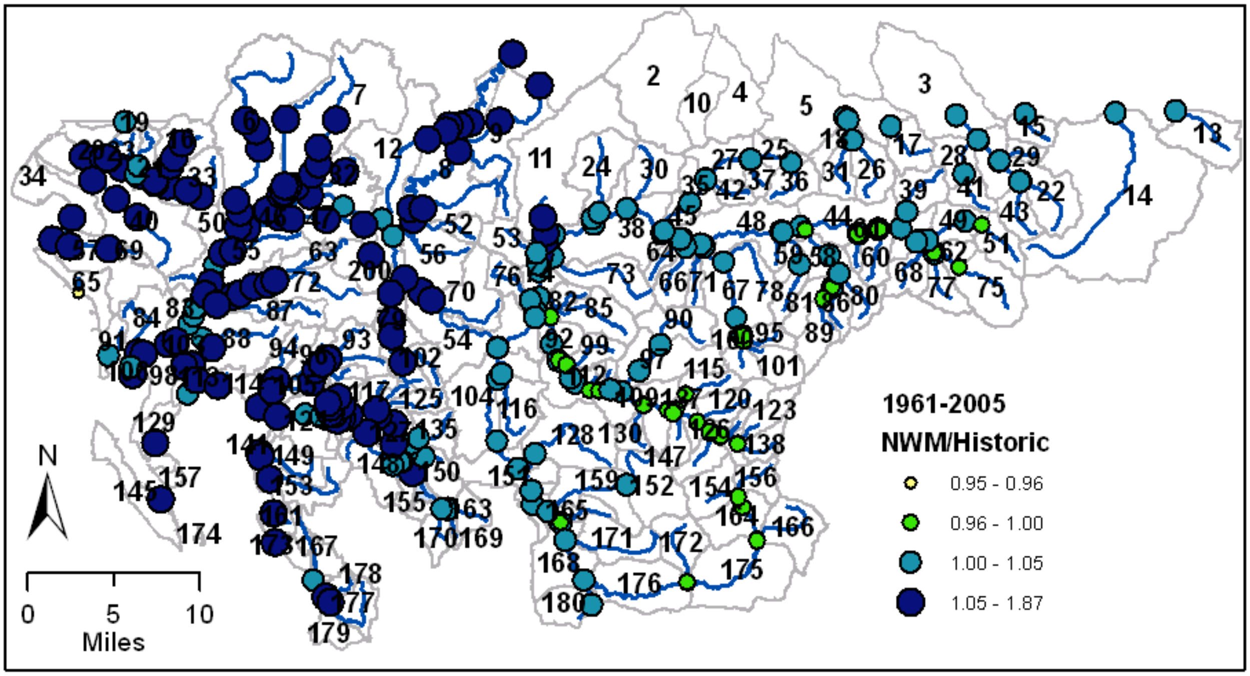


Figure 4. Ratio of simulated existing streamflow with no water management to simulated historic streamflow, 30 year average over the years 1961-2005 at each node of the WRIA 1 surface water quantity model.

In Figure 4, large blue dots represent locations where streamflow is simulated to have increased. Small yellow dots represent locations where streamflow is simulated to have been reduced. Examining this figure, one sees that there are significant increases in streamflow simulated, especially in the western parts of the watershed.

Fort Bellingham

Fort Bellingham (Figure 5, Drainage ID 114) has the greatest increase in mean streamflow from Historic to Existing NWM, a factor of 1.87 for the 45 year comparison period. This is believed to be due to a combination of the increased impervious fraction under current conditions and land cover more conducive to evaporation under Historic conditions. Developed areas have displaced areas with natural vegetation. This explanation holds for much of the western part of WRIA 1 where streamflow increases are seen. Note in Figure 5 that most of the increase in simulated streamflow appears to be due to spikiness that results from rainfall on impervious areas that runs off immediately.

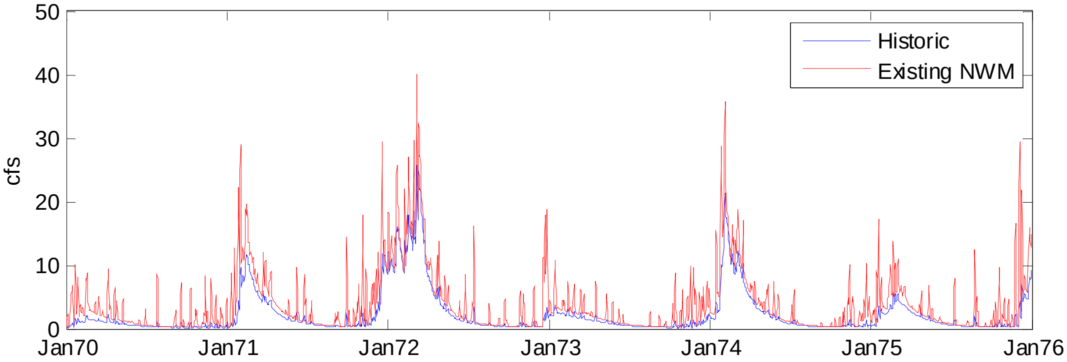
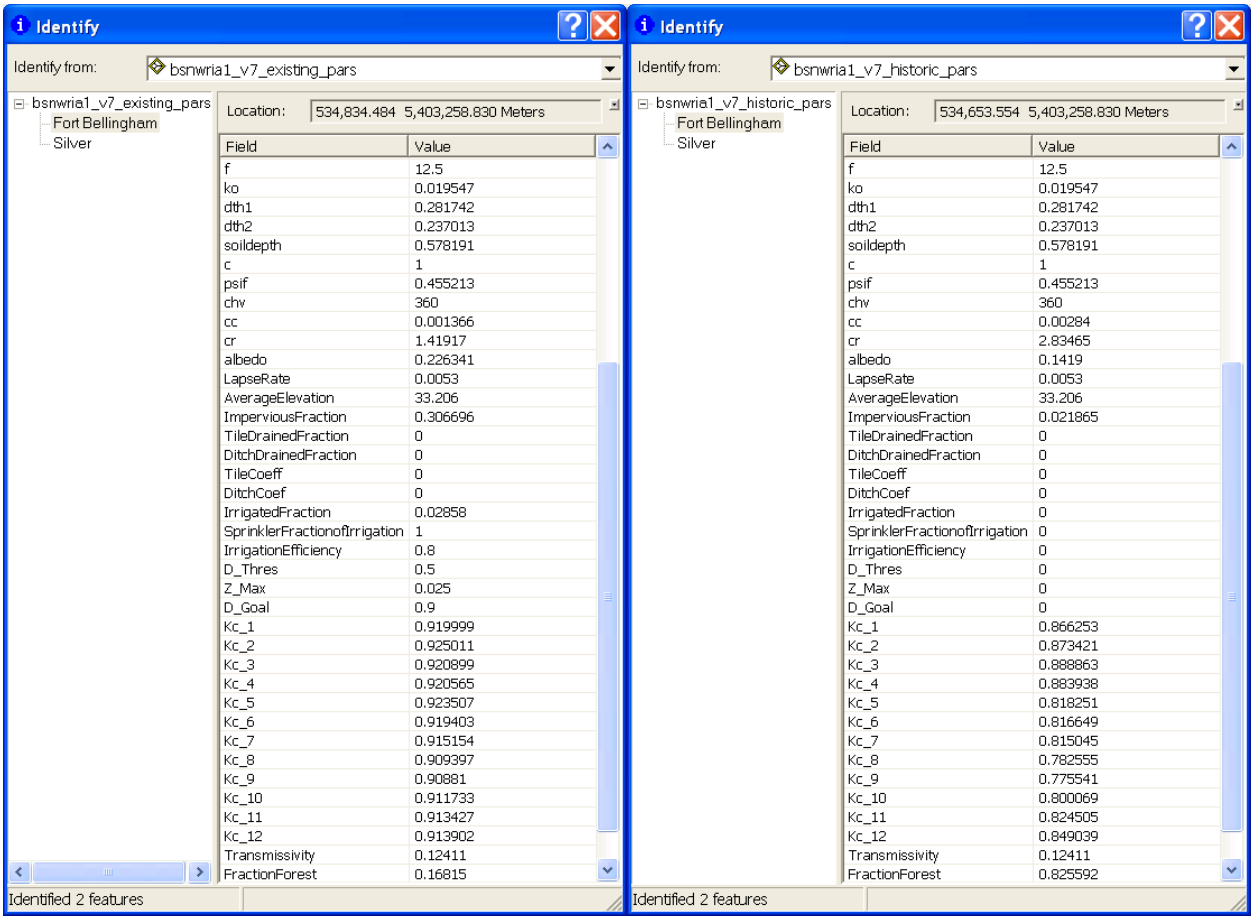


Figure 5. Historic and existing simulated streamflow at Fort Bellingham (Drainage ID 114) for the water years 1971 to 1975.



Identify from: bsnwria1_v7_existing_pars

Location: 534,834.484 5,403,258.830 Meters

Field	Value
f	12.5
ko	0.019547
dth1	0.281742
dth2	0.237013
soildepth	0.578191
c	1
psif	0.455213
chv	360
cc	0.001366
cr	1.41917
albedo	0.226341
LapseRate	0.0053
AverageElevation	33.206
ImperviousFraction	0.306696
TileDrainedFraction	0
DitchDrainedFraction	0
TileCoeff	0
DitchCoef	0
IrrigatedFraction	0.02858
SprinklerFractionofIrrigation	1
IrrigationEfficiency	0.8
D_Thres	0.5
Z_Max	0.025
D_Goal	0.9
Kc_1	0.919999
Kc_2	0.925011
Kc_3	0.920899
Kc_4	0.920565
Kc_5	0.923507
Kc_6	0.919403
Kc_7	0.915154
Kc_8	0.909397
Kc_9	0.90881
Kc_10	0.911733
Kc_11	0.913427
Kc_12	0.913902
Transmissivity	0.12411
FractionForest	0.16815

Identified 2 features

Identify from: bsnwria1_v7_historic_pars

Location: 534,653.554 5,403,258.830 Meters

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ko	0.019547
dth1	0.281742
dth2	0.237013
soildepth	0.578191
c	1
psif	0.455213
chv	360
cc	0.00284
cr	2.83465
albedo	0.1419
LapseRate	0.0053
AverageElevation	33.206
ImperviousFraction	0.021865
TileDrainedFraction	0
DitchDrainedFraction	0
TileCoeff	0
DitchCoef	0
IrrigatedFraction	0
SprinklerFractionofIrrigation	0
IrrigationEfficiency	0
D_Thres	0
Z_Max	0
D_Goal	0
Kc_1	0.866253
Kc_2	0.873421
Kc_3	0.888863
Kc_4	0.883938
Kc_5	0.818251
Kc_6	0.816649
Kc_7	0.815045
Kc_8	0.782555
Kc_9	0.775541
Kc_10	0.800069
Kc_11	0.824505
Kc_12	0.849039
Transmissivity	0.12411
FractionForest	0.825592

Identified 2 features

Figure 6. Model parameters for Fort Bellingham Drainage (ID 114) for Existing (left) and Historic (right) conditions displayed by the GIS.

Model parameters for the Fort Bellingham drainage are given in Figure 6. The significant parameter differences are the fraction that is forest (0.82 vs. 0.17) which, although not directly used in the model, results in significant differences in albedo (0.14 vs. 0.23), interception evaporation factor, Cr (2.83 vs 1.42) and impervious fraction (0.02 vs. 0.31) parameters. These result in the historic evaporation being simulated as more and the historic streamflow being simulated as less. Figure 7 gives the simulated cumulative streamflow, evaporation and precipitation for Fort Bellingham.

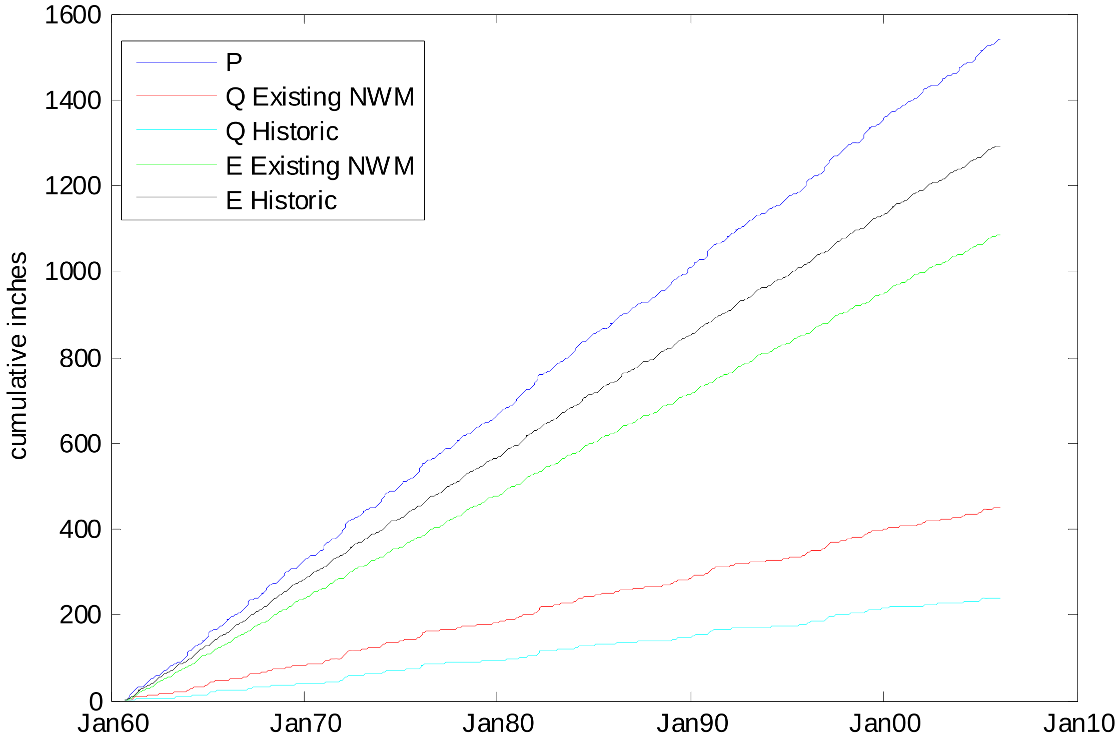


Figure 7. Fort Bellingham cumulative water balance components simulated under Historic and Existing conditions without water management. P=Precipitation, Q=Streamflow, E=Evapotranspiration.

Figure 7 shows that the historic evaporation is simulated as being more due to smaller albedo, greater forest fraction, and interception losses, resulting in lower streamflow. Figure 8 and Figure 9 below show the land use over the Fort Bellingham Drainage for Historic and Existing condition simulations. These figures show the dramatic changes in land use that have occurred with development that lead to this drainage having a great increase in runoff production.

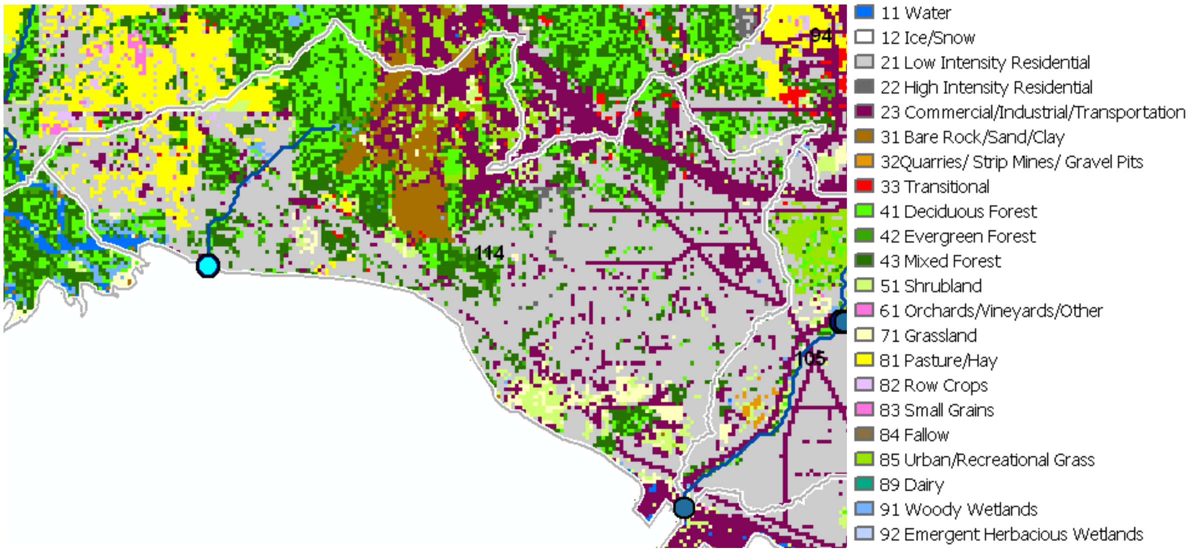


Figure 8. Fort Bellingham Existing Conditions LULC.

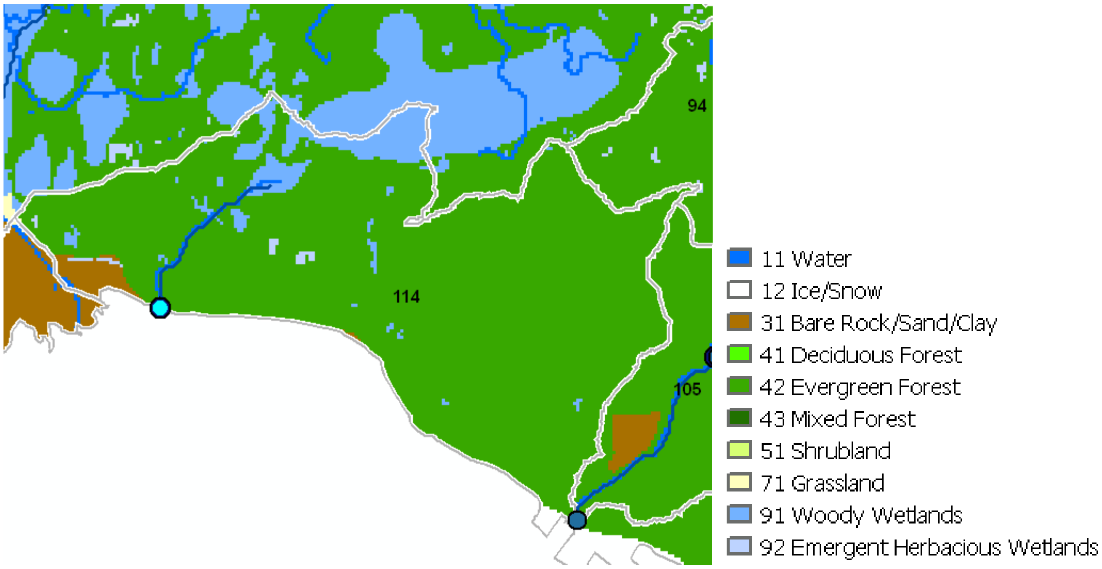


Figure 9. Fort Bellingham Historic Conditions LULC.

Bertrand Creek Comparisons

Another drainage that was examined is Bertrand Creek, DrainID=6. The outlet is ProjNodeID=515. (There are two node numbering systems in use. The first, referred to as ProjNodeID corresponds to the node numbers in points_of_interest_v8.shp used by WRIA 1. The second, referred to as NodeID is an internal numbering system used by TOPNET. The correspondence between these numbering systems is established in the nodelinks.txt file and is described in the accompanying report "Surface Water Quantity Model Development and Calibration". In this report, for consistency, when we refer to a node number, we use the ProjNodeID numbering.)

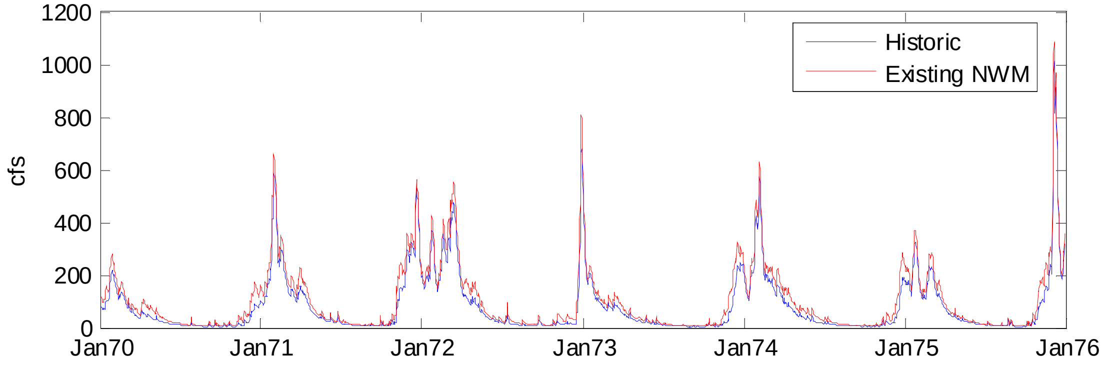


Figure 10. Historic and existing simulated streamflow at the Bertrand Creek outlet (ProjNodeId=515)

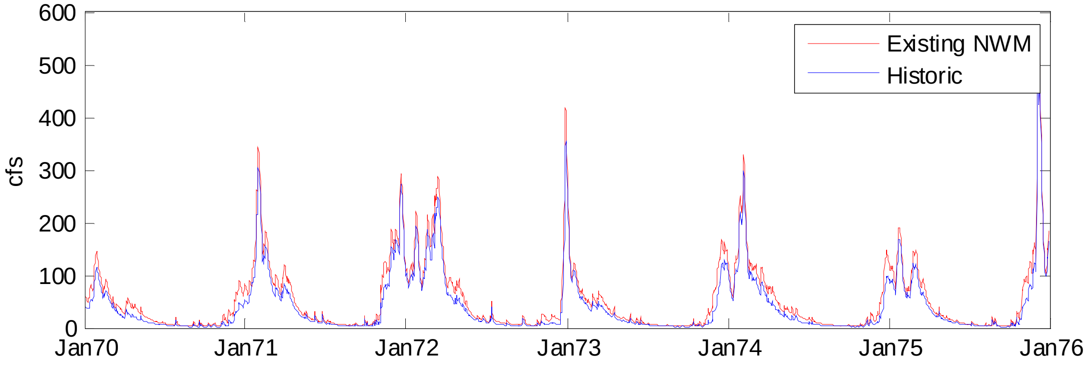


Figure 11. Historic and existing simulated streamflow at intensive site within Bertrand Creek (ProjNodeId=401)

Figure 10 and Figure 11 illustrate the change in simulated streamflow for Bertrand Creek for Existing NWM and Historic conditions. The mean flows over the 45 years (1961-2005) for the different simulations are:

Scenario	ProjNode 401	ProjNode 515
	cfs	cfs
Existing:	47.3	87.0
Historic:	39.1	75.2
Existing No Management	51.1	98.2
Full Buildout	48.0	86.2

Increases are simulated for the Existing and Full Buildout conditions relative to Historic, mainly due to reductions in ET with the changes in vegetation type. There are also some changes due to management. In the model irrigation withdrawals are taken from the drainage outlet, which in this case is Node 515. These amount to on average 17.8 cfs. The reduction in flow between Existing and Existing with no management of 11.2 cfs is less than this due to irrigation return flows that the model computes in the rainfall runoff transformation component. Irrigation is applied to the surface just as rainfall and can infiltrate, evapotranspire, or runoff with return flows being runoff and increases in baseflow due to infiltration that reaches the subsurface groundwater store. Figure 12 gives the changes in flow distribution curves for two illustrative months. Flow distribution data for these two nodes for all months are given in the spreadsheet Bertrand_Exceedance.xls included in the electronic appendix. Note that these distributions show that according to the simulations flow under Existing and Full Buildout conditions is in general in Bertrand Creek, increased over Historic conditions due to reduced evapotranspiration. However, in October, a low flow month, withdrawals simulated for Existing and Full Buildout conditions do reduce flow below Historic at the low end of the distribution. According to these simulations, there is for Existing conditions about a 15% probability of flow being 0 on any day in October unless user withdrawals are reduced. For Full Buildout conditions this probability increases to about 20%. Note that these zero flows do not show up at the internal node, ProjNode 401, due to the drainage level discretization in the model that takes irrigation surface water withdrawals from the outlet.

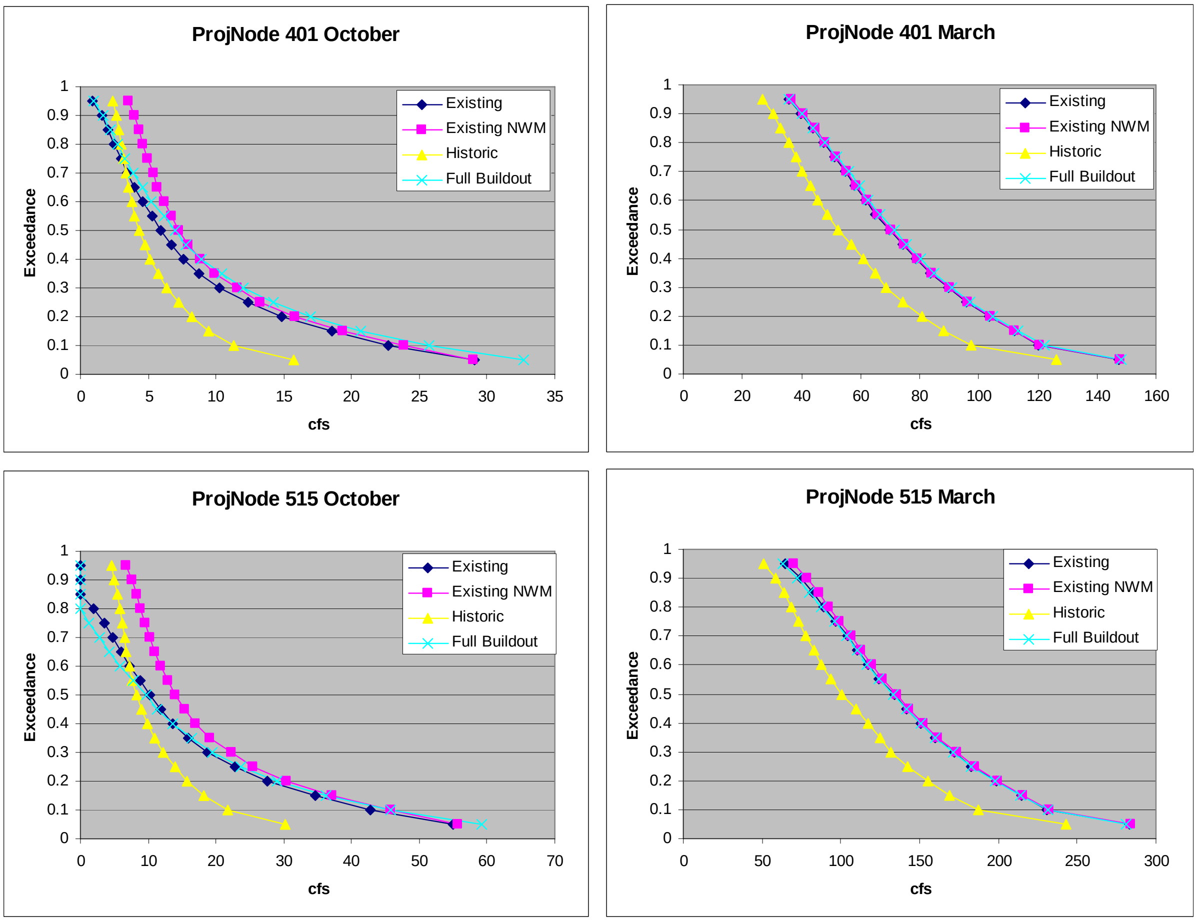


Figure 12. Flow duration curves for October and March in Bertrand Creek.

Figure 13 and Figure 14 show Existing and Historic LULC for the Bertrand Creek area. Figure 15 shows the model parameters derived from this LULC. Note the differences in albedo, ditch drained fraction, crop coefficients, and interception evaporation enhancement factor C_r. Figure 16 shows the cumulative water balance components for the Bertrand Creek drainage as simulated for the period 1961-2005.

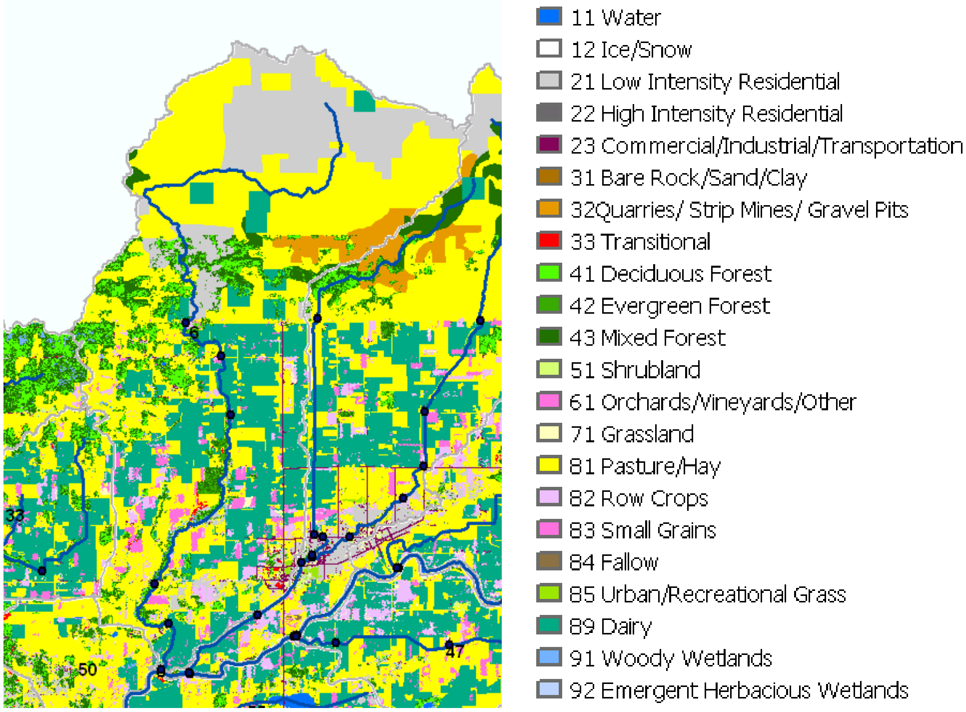


Figure 13. Bertrand Creek Existing Conditions Land Cover

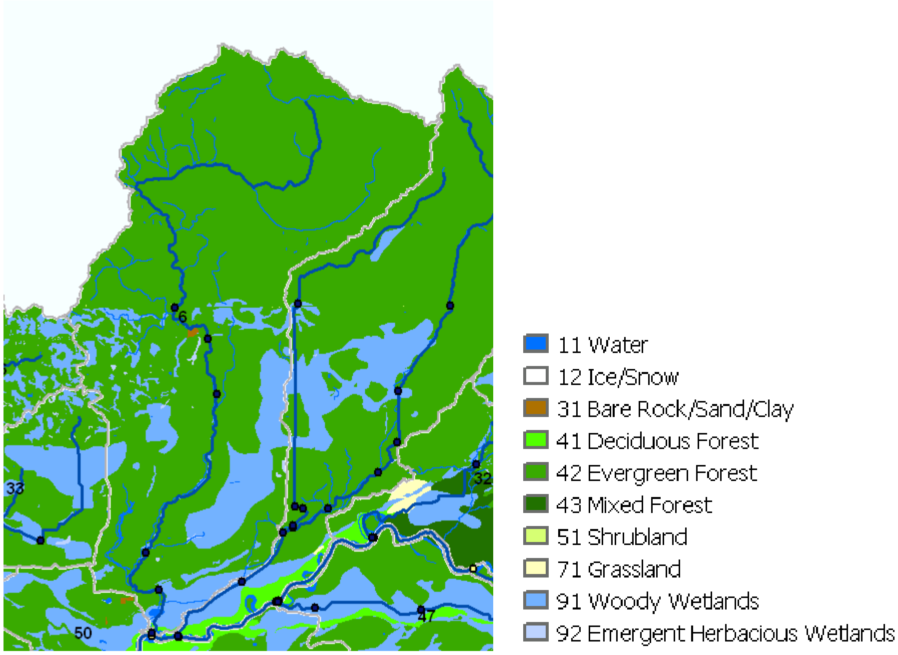
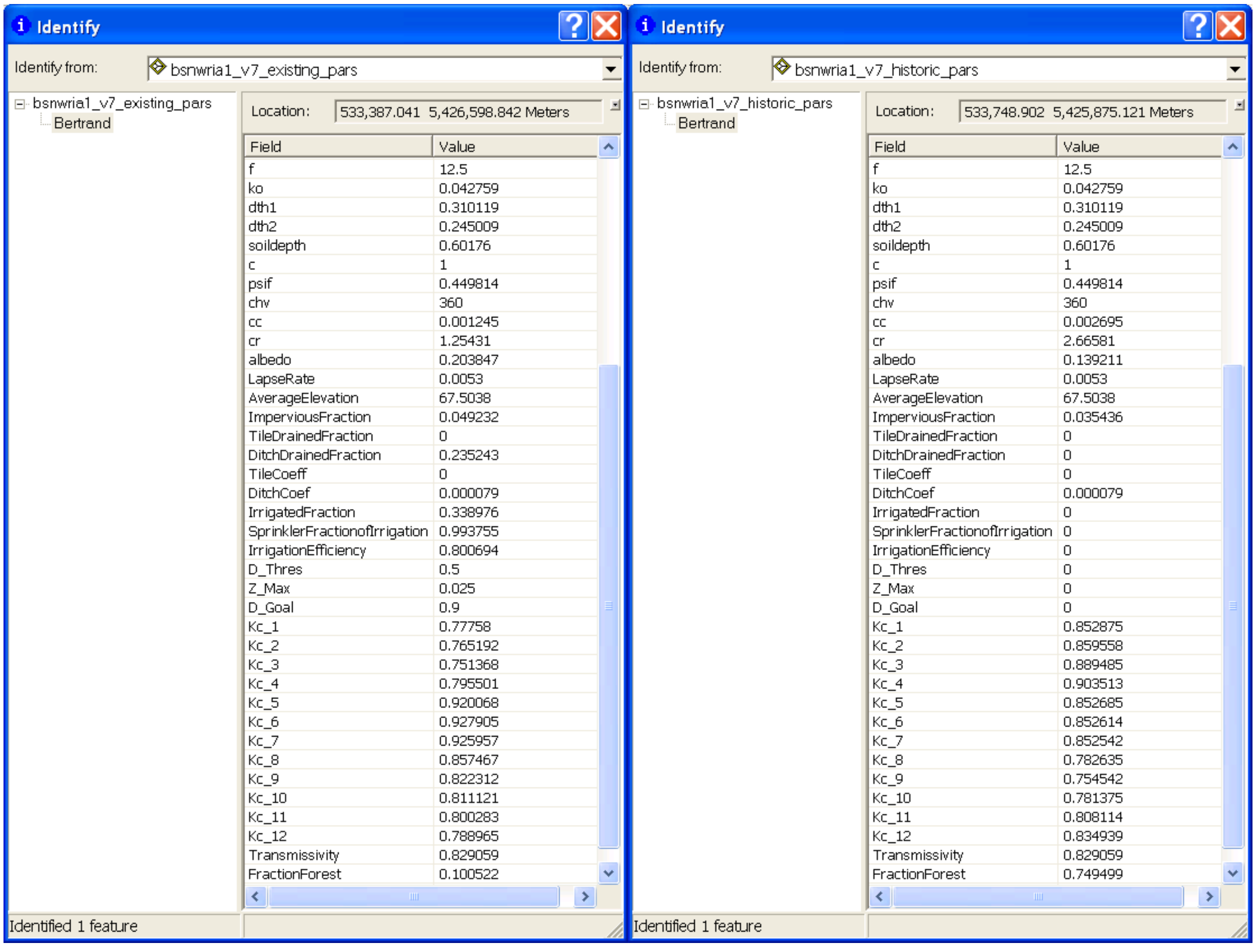


Figure 14. Bertrand Creek Historic Conditions Land Cover



Identify from: bsnwria1_v7_existing_pars

bsnwria1_v7_existing_pars
Bertrand

Location: 533,387.041 5,426,598.842 Meters

Field	Value
f	12.5
ko	0.042759
dth1	0.310119
dth2	0.245009
soildepth	0.60176
c	1
psif	0.449814
chv	360
cc	0.001245
cr	1.25431
albedo	0.203847
LapseRate	0.0053
AverageElevation	67.5038
ImperviousFraction	0.049232
TileDrainedFraction	0
DitchDrainedFraction	0.235243
TileCoeff	0
DitchCoef	0.000079
IrrigatedFraction	0.338976
SprinklerFractionofIrrigation	0.993755
IrrigationEfficiency	0.800694
D_Thres	0.5
Z_Max	0.025
D_Goal	0.9
Kc_1	0.77758
Kc_2	0.765192
Kc_3	0.751368
Kc_4	0.795501
Kc_5	0.920068
Kc_6	0.927905
Kc_7	0.925957
Kc_8	0.857467
Kc_9	0.822312
Kc_10	0.811121
Kc_11	0.800283
Kc_12	0.788965
Transmissivity	0.829059
FractionForest	0.100522

Identified 1 feature

Identify from: bsnwria1_v7_historic_pars

bsnwria1_v7_historic_pars
Bertrand

Location: 533,748.902 5,425,875.121 Meters

Field	Value
f	12.5
ko	0.042759
dth1	0.310119
dth2	0.245009
soildepth	0.60176
c	1
psif	0.449814
chv	360
cc	0.002695
cr	2.66581
albedo	0.139211
LapseRate	0.0053
AverageElevation	67.5038
ImperviousFraction	0.035436
TileDrainedFraction	0
DitchDrainedFraction	0
TileCoeff	0
DitchCoef	0.000079
IrrigatedFraction	0
SprinklerFractionofIrrigation	0
IrrigationEfficiency	0
D_Thres	0
Z_Max	0
D_Goal	0
Kc_1	0.852875
Kc_2	0.859558
Kc_3	0.889485
Kc_4	0.903513
Kc_5	0.852685
Kc_6	0.852614
Kc_7	0.852542
Kc_8	0.782635
Kc_9	0.754542
Kc_10	0.781375
Kc_11	0.808114
Kc_12	0.834939
Transmissivity	0.829059
FractionForest	0.749499

Identified 1 feature

Figure 15. Model parameters for Bertrand Creek Drainage (ID 6) for Existing (left) and Historic (right) conditions displayed by the GIS.

Examination of the Bertrand Creek model parameters indicates that the fraction that was forest under Historic conditions is much higher than Existing conditions. The lower albedo and higher interception evaporation factor (C_r) results in greater ET and correspondingly lower streamflow for the Historic scenario. Also the Existing NWM simulation has artificial drainage over the areas depicted in Figure 3. This tends to remove water more rapidly to streams – water that may otherwise have been held in the landscape and eventually lost to evapotranspiration.

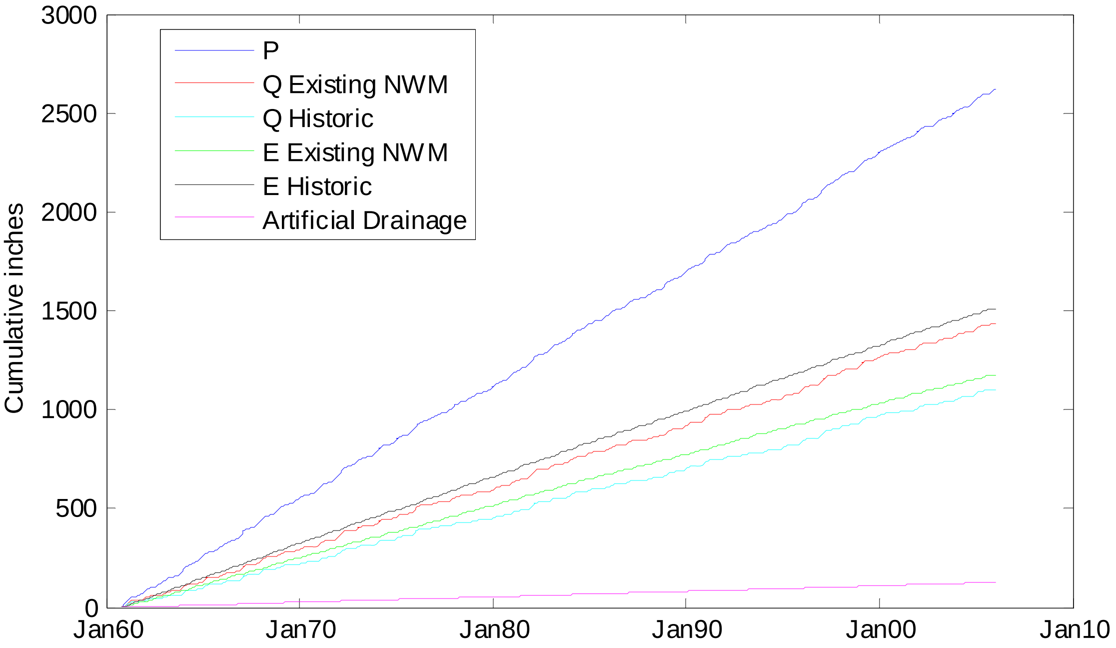


Figure 16. Bertrand Creek cumulative water balance components simulated under Historic and Existing NWM conditions without water management. P=Precipitation, Q=Streamflow, E=Evapotranspiration.

Deer Creek Comparisons

Another drainage that was examined is Deer Creek, DrainID=87. ProjNodeID=164. For Deer Creek, the ratio of Historic to unmanaged Existing conditions streamflow is 1.38. Figure 17 shows the change in simulated flow for Bertrand Creek for Existing NWM and Historic conditions. Figure 18 shows the cumulative water balance components as simulated for the period 1961-2005.

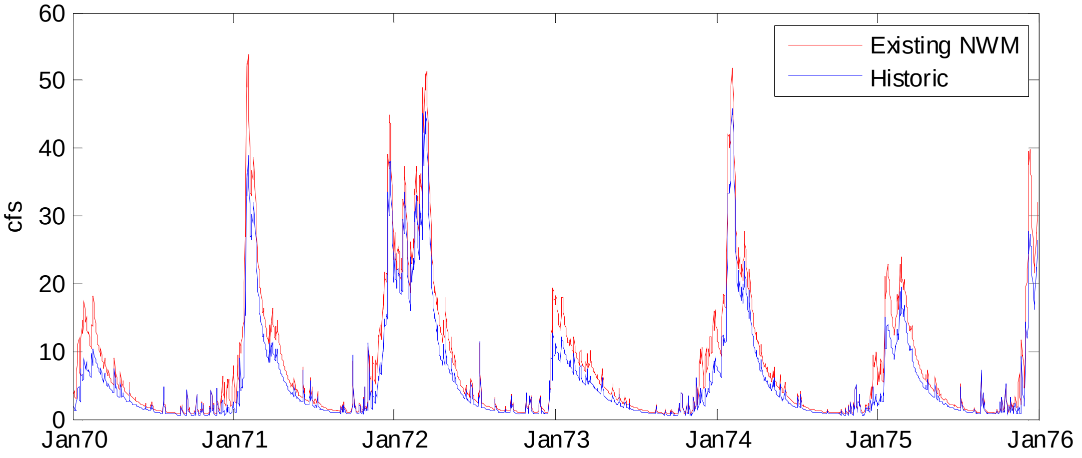


Figure 17. Historic and simulated streamflow at Deer Creek

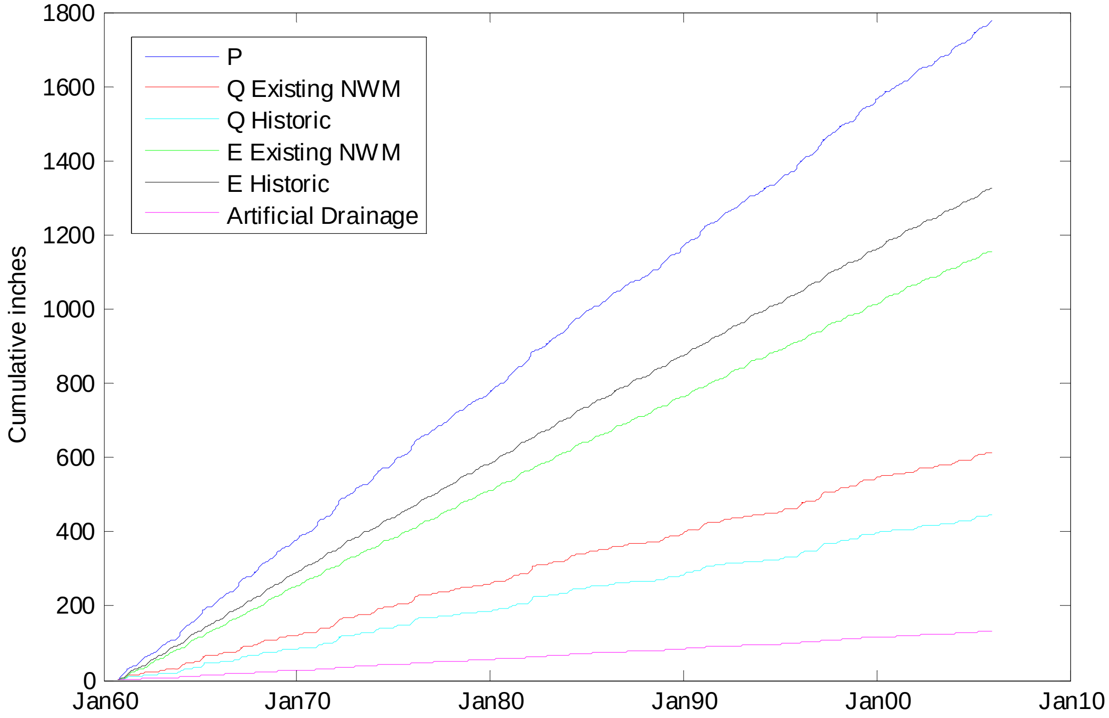


Figure 18. Deer Creek cumulative water balance components simulated under Historic and Existing conditions without water management.

Here, artificial drainage plays a significant role in the increase in runoff under Existing conditions without water management. Artificial drainage is modeled to remove water from the surface and soil resulting in lower evaporation.

Comparison of Existing to Existing NWM

To examine the direct impact of Water Management, this section compares the scenario simulated under Existing conditions with and without water management being modeled. Figure 19 presents a map depicting the difference in mean streamflow over the 30 year simulation period (1961-2005) between the Existing and Existing NWM simulations.

The most significant impact is an increase in discharge into and through Lake Whatcom due to the Middle Fork diversion as illustrated in Figure 20. The flow out of Drainage 163, Anderson/Whatcom, the drainage that discharges into Lake Whatcom, is increased by a factor of 2.57 due to management, primarily the Middle Fork diversion. Note also in Figure 19 that there are significant reductions in average flows in the western part of the watershed due to water use withdrawals. These reductions are up to as much as 48 % in the highest instances.

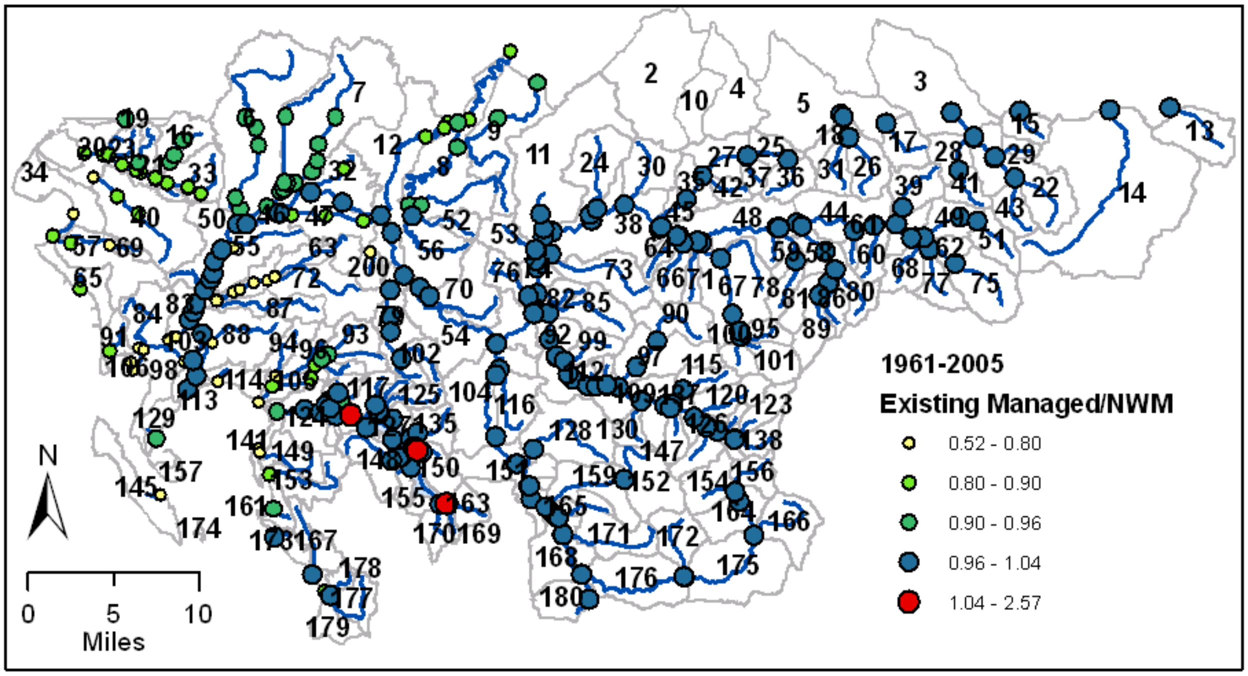


Figure 19. Ratio of simulated streamflow under existing conditions to simulated streamflow under existing conditions without water management.

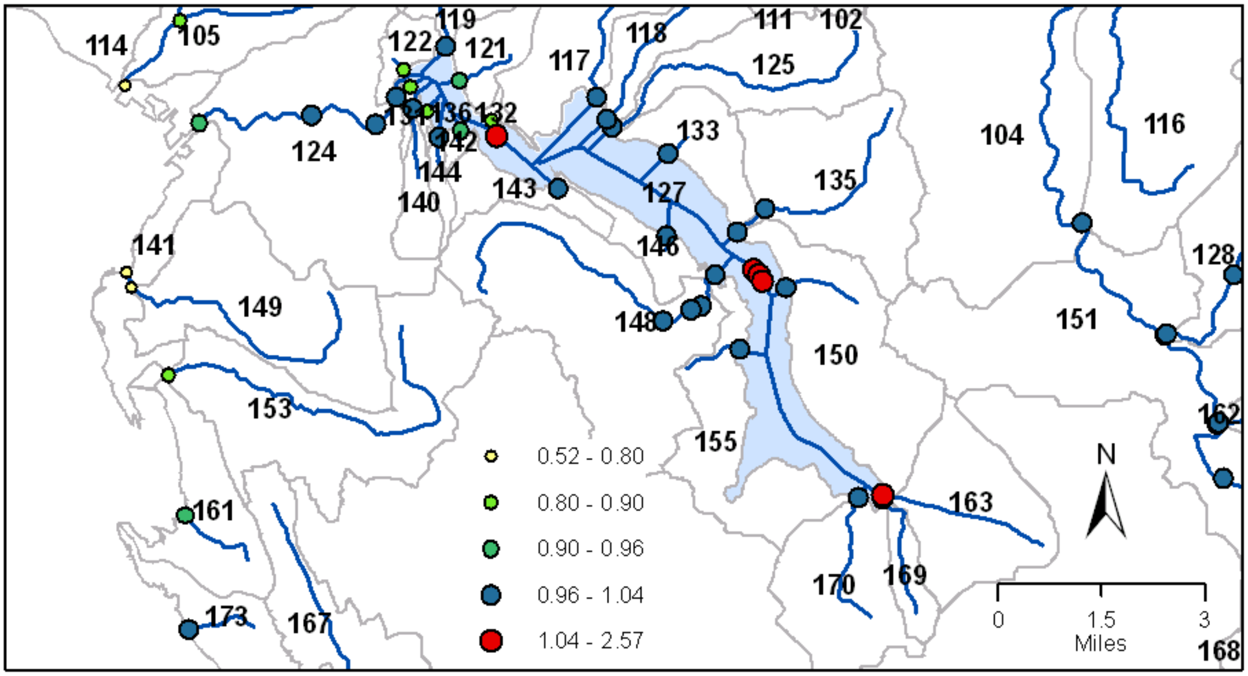


Figure 20. Ratio of simulated streamflow under existing conditions to simulated streamflow under existing conditions without water management in the Lake Whatcom area..

Middle Fork Diversion

The following table gives the user inputs that define the Middle Fork diversion. A demand rate of 42277 m^3/day is specified. This amounts to 0.49 m^3/s or 17.3 cfs. This rate was determined from the recorded total diversion of 8154 million gallons over the two years 1999 and 2000.

Table 3. User.txt and Source.txt file contents specifying Middle Fork diversion

user.txt

UserId	UserType	POU_ID	DemandVble	DemandRate	InYearDemandType	ReturnFlowID	SourceMixingId	NumSources	SourceID1	TypeName
527	11	163	1	42277	4	21	0	1	47	Diversion

source.txt

SourceID	Type	SourceL	PhysicalDai	PhysicalAnnMax
47	1	109	1.00E+20	1.00E+20

Figure 21 and Figure 22 show the impact of the Middle Fork diversion on streamflow hydrographs at the diversion location on the Middle Fork River.

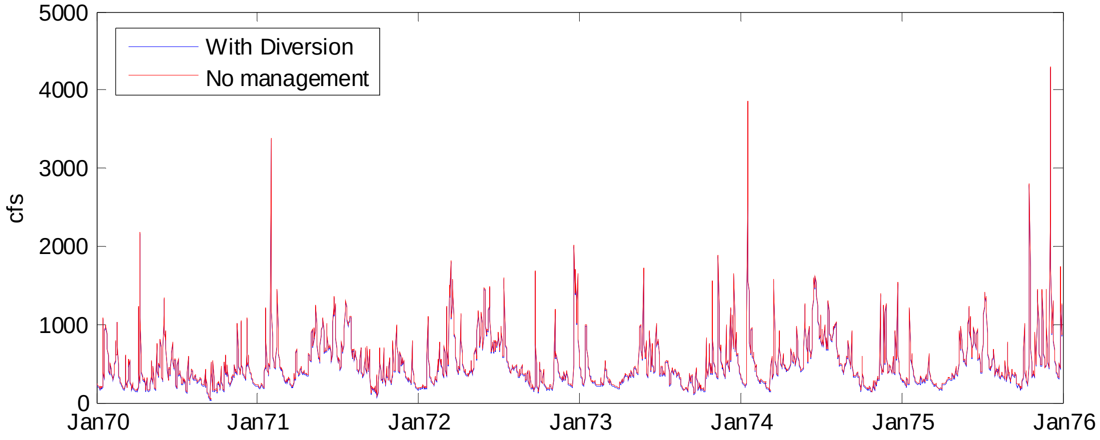


Figure 21. Streamflow at ProjnodeID=185, Drainage 109, location of Middle Fork Diversion.

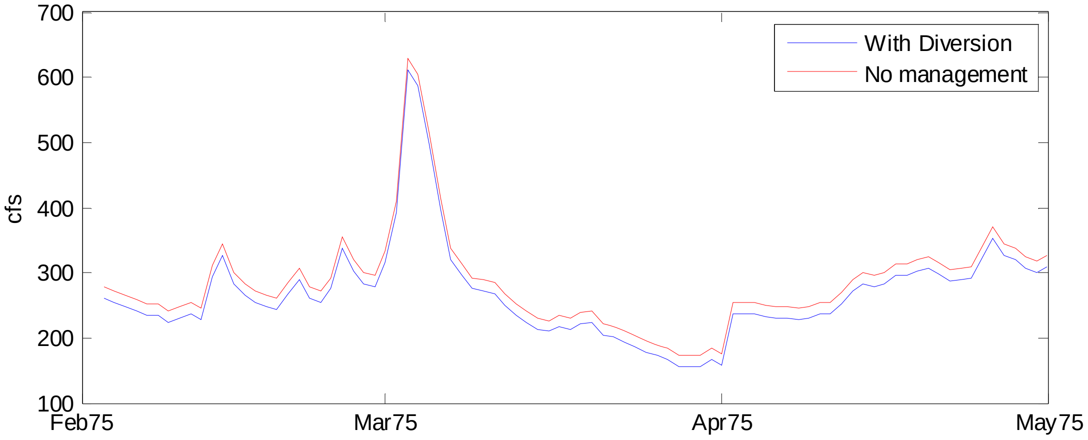


Figure 22. Expanded view of streamflow at ProjnodeID=185, Drainage 109, location of Middle Fork Diversion.

From these figures, we conclude that the 17.3 cfs diversion has very small impact on flow in the Middle Fork. Figure 23, however, shows that flows in Anderson Creek, where the diversion discharges, are significantly increased.

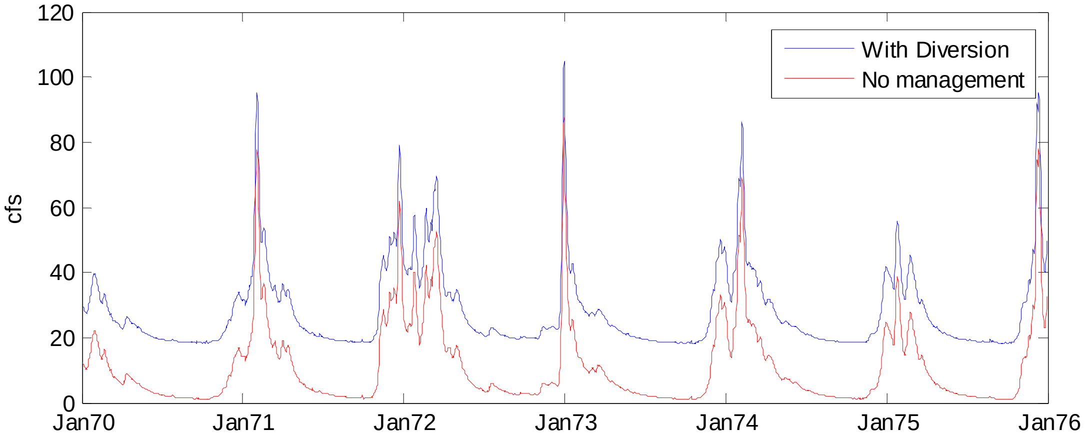


Figure 23. Streamflow at ProjnodeID=519, Drainage 163, location where Middle Fork Diversion discharges into Anderson Creek.

Deer Creek

The impact of water management in Deer Creek was examined. Table 4 shows the portions of the water management input files that pertain to Deer Creek (Drainage 87, ProjNodeId 164).

The flow out of Drainage 87, Deer Creek at Node 164 is reduced by a factor of 0.65 due to the impact of these users. Figure 24 shows the simulated hydrograph at this location, with and without water management. Note the reductions in flow due to water use, resulting in zero flow at certain times. Table 4 indicates that there are four users that take water from Deer Creek.

Figure 25 shows the user withdrawals from Deer Creek. At times when streamflow is 0, the user demands upon streamflow can not be fully met. Figure 26 shows the irrigation user deficit.

Table 4. Water Management Tables for Deer Creek

User.txt

UserId	UserType	POU_ID	DemandVble	DemandRate	InYear DemandType	ReturnFlowID	Source MixingId	NumSources	SourceID1	SourceID2	UserType
218	5	87	960	0.3785	1	1	0	1	264	0	Self Supplied Res
339	5	87	105.64	13.4	2	2	1	2	264	92	Self Supplied CIT
436	1	87	4E+06	0.004	5	-1	3	2	264	92	Irrigation
517	6	87	129	0.0757	3	3	2	2	264	92	Dairy

Source.txt

SourceID	Type	SourceLocationID	Physical DailyMax	Physical AnnMax
92	1	87	1E+20	1E+20
264	2	87	1E+20	1E+20

ReturnFlow.txt

ReturnFlowID	NumReturn Flows	ReturnFlow Units	ReturnFlow Amt1	ReturnFlow Type1	ReturnFlow Locn1	ReturnFlow WWTPID1
1	1	1	0.05	2	0	0
2	1	1	0.1	2	0	0
3	1	1	0.1	2	0	0

SourceMixing.txt

Source MixingID	Users Source Num	Units	Amount	Season Number	SeasonsDefnID
1	1	1	0.2	1	1
1	2	1	0.8	1	1
2	1	1	0.2	1	1
2	2	1	0.8	1	1
3	1	1	0.7	1	1
3	2	1	0.3	1	1

MonthlyDemandFraction.txt

InYear Demand Type	Month1	Month2	Month3	Month4	Month5	Month6	Month7	Month8	Month9	Month10	Month11	Month12
1	0.8	0.8	0.8	0.7	1	1	1	1	0.7	0.8	0.8	0.8
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0.25	0.5	0.75	1	1	0.5	0	0	0

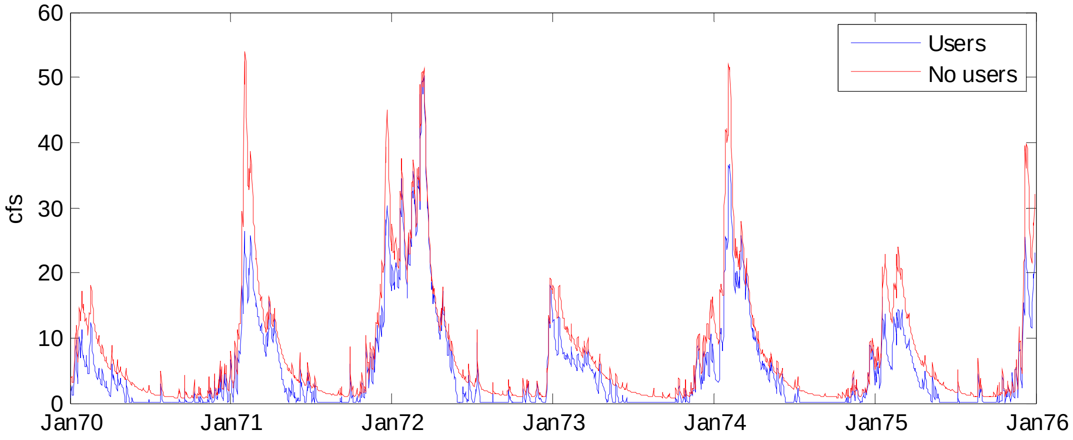


Figure 24. Streamflow at ProjnodeID=164, Drainage 87, Deer Creek.

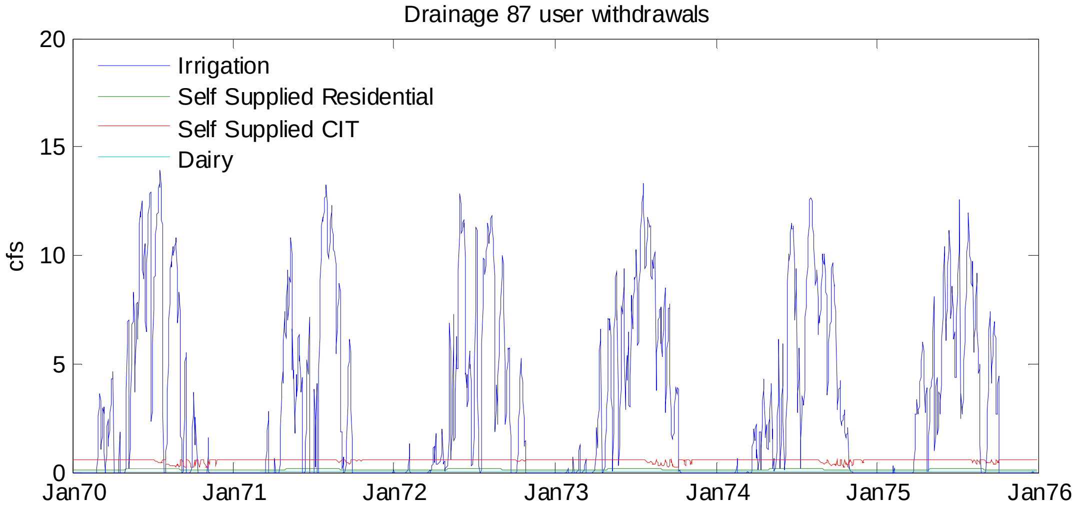


Figure 25. Existing conditions simulation of user withdrawals from Deer Creek Drainage (Drainage 87)

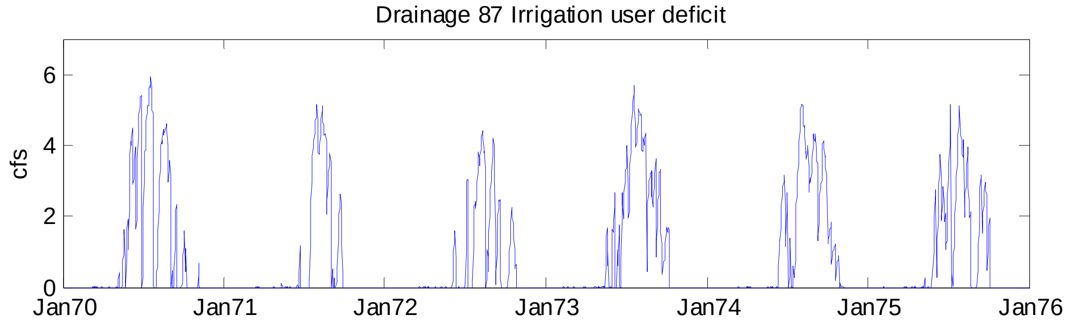


Figure 26. Existing conditions simulation of irrigation user deficit (unmet demand) from Deer Creek Drainage (Drainage 87)

Irrigation user deficit occurs when streamflow is limited due to the source mixing between surface and groundwater being 30%: 70%. This results in a higher fraction of groundwater being used for irrigation during these deficit periods. Also, since the irrigation demand is soil moisture driven, irrigation from groundwater continues to keep the soil moisture at the target level.

Figure 27 shows the simulated deficits in non-irrigation demands. Note that there is no deficit in self-supplied residential due to it being completely taken from groundwater (SourceID=264 in the User.txt file, Table 4, refers to a source of Type 2 with LocationID 87 indicating groundwater from Deer Creek Drainage) . Self-supplied commercial, industrial and transportation users, as well as Dairy users, experience deficits due to them having an assumed 20% drawn from surface water. This is indicated in the users.txt table (Table 4) by them having two identified sources and reference to a source mixing table record that specifies the sharing of take between sources. There is some irregularity in these deficits due to the model arbitrarily assigning deficits between different users.

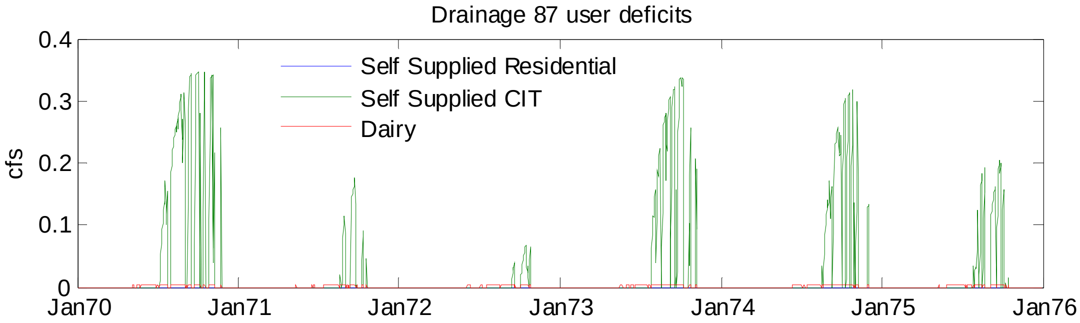


Figure 27. Existing conditions simulation of non irrigation deficits (unmet demands) from Deer Creek Drainage (Drainage 87).

Figure 28 shows the non-irrigation user demands simulated for Deer Creek Drainage. Note the seasonal cycle in self-supplied residential demands due to the monthly factors given in MonthlyDemandFraction.txt for InYearDemandType 1 (Table 4) that corresponds to residential users.

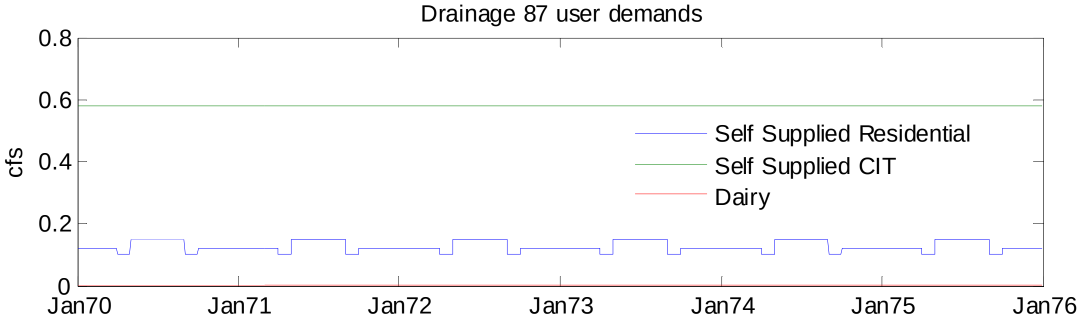


Figure 28. Existing conditions simulation of non irrigation demands from Deer Creek Drainage (Drainage 87).

Full Buildout Scenario

To examine the potential impact of growth to Full Buildout conditions, this section compares the scenario simulated under Full Buildout conditions to that simulated under Existing conditions. Figure 29 shows the ratio of mean streamflow over the 45 year simulation period (1961-2005) between Full Buildout and Existing condition simulations.

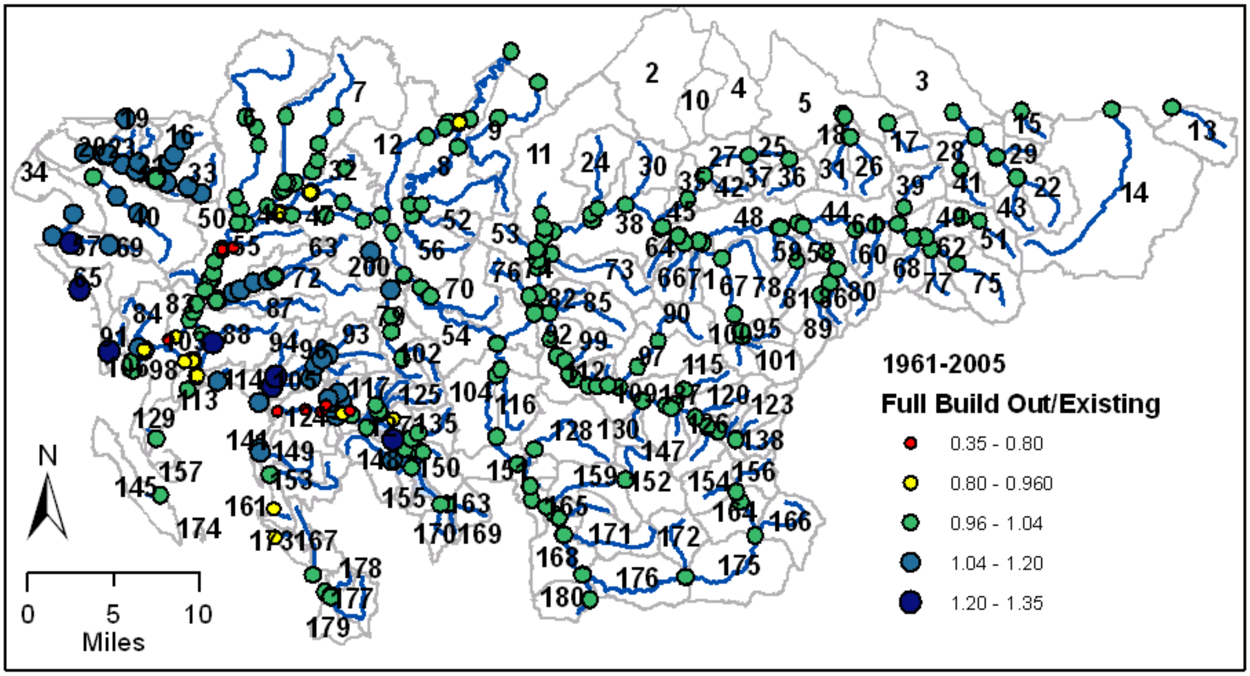


Figure 29. Ratio of mean streamflow simulated under Full Buildout conditions to mean streamflow simulated under existing conditions.

In this comparison of Full Buildout to Existing conditions simulations, the most significant reductions are at the outflow from Lake Whatcom and Drainage 55 (Wiser Lake/Cougar Creek). The model treats Lake Whatcom as a reservoir. Figure 30 shows the simulations of active storage in Lake Whatcom for these scenarios.

It is interesting to note that under the simulation of Existing conditions, the storage in Lake Whatcom is rarely tapped in to, while for the Full Buildout Scenario, it is extensively drawn upon. Figure 31 shows the discharge from Lake Whatcom. Note the minimum release of 10 cfs specified as the required instream flow for the fish hatchery. Under Existing conditions, releases are often above this minimum release, while under Full Buildout Conditions, flow at the minimum release level is quite common.

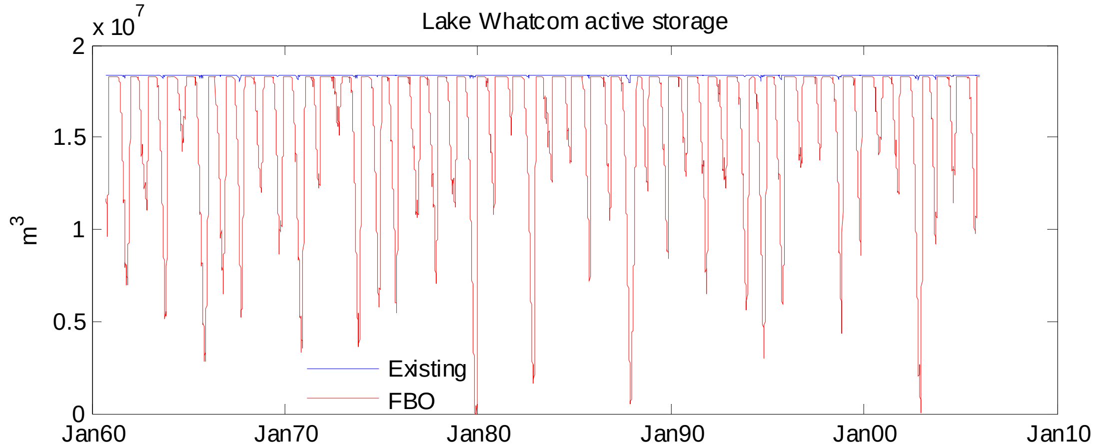


Figure 30. Existing and Full Buildout scenario simulations of Lake Whatcom active storage.

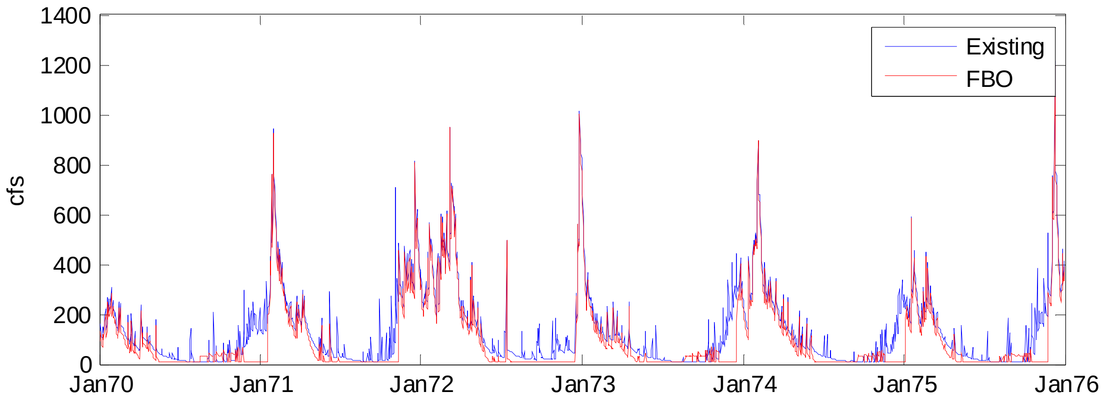


Figure 31. Discharge from Lake Whatcom (Node 246).

In considering the storage in and release from Lake Whatcom, it is interesting to examine the associated user demands (Figure 32).

There are a total of 46 users that draw upon Lake Whatcom, plus an instream demand of 10.5 cfs for the Fish Hatchery. Bellingham is the largest of these users. There is an increase in total demand from Lake Whatcom from around 20 cfs to around 50 cfs from Existing to Full Buildout conditions. This results in the reductions in lake storage and discharge seen in Figure 31 and Figure 32. The pattern in these demands is due to the monthly demand cycle for residential users specified in the MonthlyDemandFraction.txt file.

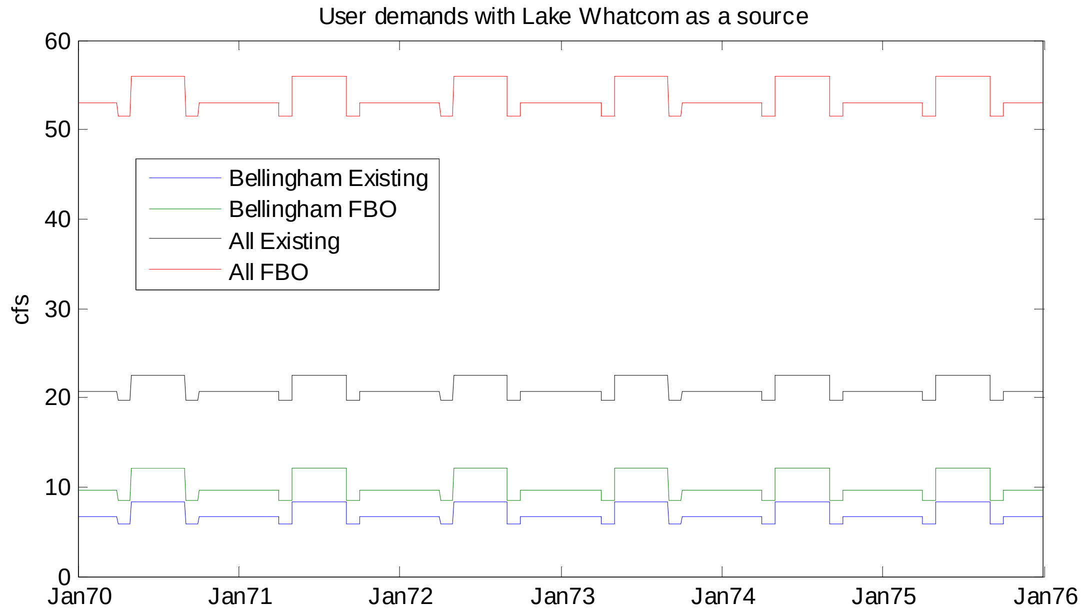


Figure 32. Demands from users with Lake Whatcom as a source

Historic, Existing and Full Buildout Comparisons

Figure 33 shows the observed streamflow in the Nooksack River at Ferndale, together with simulated Historic, Existing and Full Buildout scenarios streamflow. Ferndale is the last streamgage on the Nooksack River before the outlet to the ocean. The lines on this graph are practically indistinguishable, indicating that, at the aggregate level of the entire watershed, the impacts of changes are modeled to be minimal.

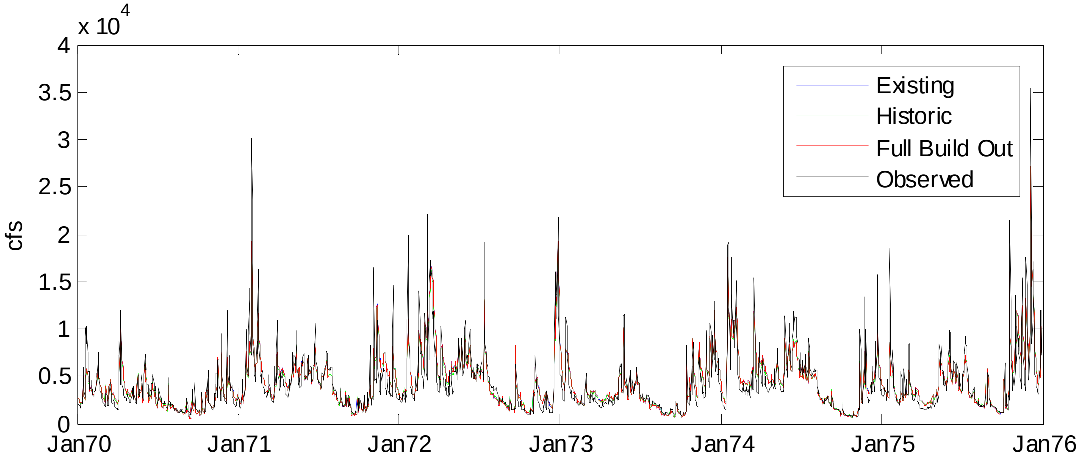


Figure 33. Observed and Simulated Existing, Historic and Full Buildout Scenario Streamflow in the Nooksack River at Ferndale (ProjNodeId=38).

Figure 34 shows simulated Historic, Existing and Full Buildout streamflow in Deer Creek. The blue Existing simulations line is essentially underneath the black Full Buildout line, so it is hard to distinguish, but the difference from Historic is apparent. This is presented as an example of the impact of development on Streamflow as simulated by the model in this lowland agricultural watershed with some urban development. This shows, for this smaller watershed with irrigated agriculture, that during the low flow months, significant streamflow depletions were simulated.

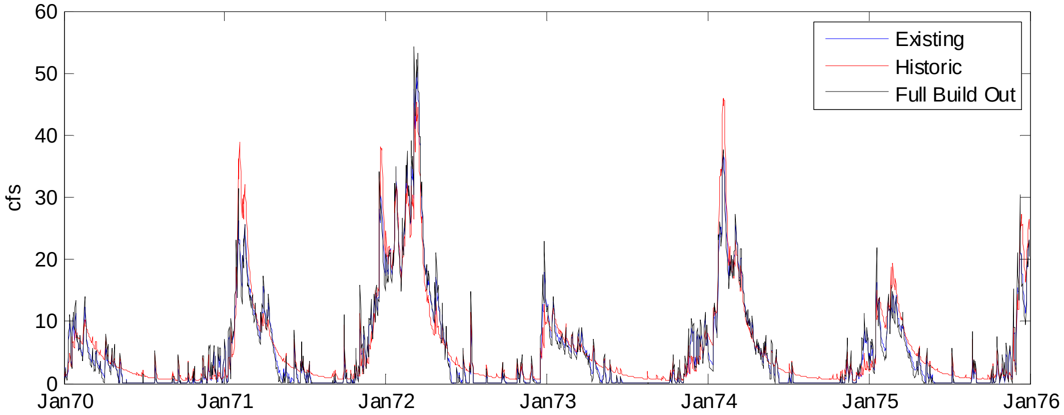


Figure 34. Simulated Historic, Existing and Full Buildout Deer Creek Streamflow (ProjNodeID=164)

Bertrand Creek Water Balance

The complete water balance for Bertrand Creek was examined to illustrate the simulated impact of Existing and Full Buildout water management. Figure 35 shows the simulated Historic, Existing, and Full Buildout streamflow in Bertrand Creek.

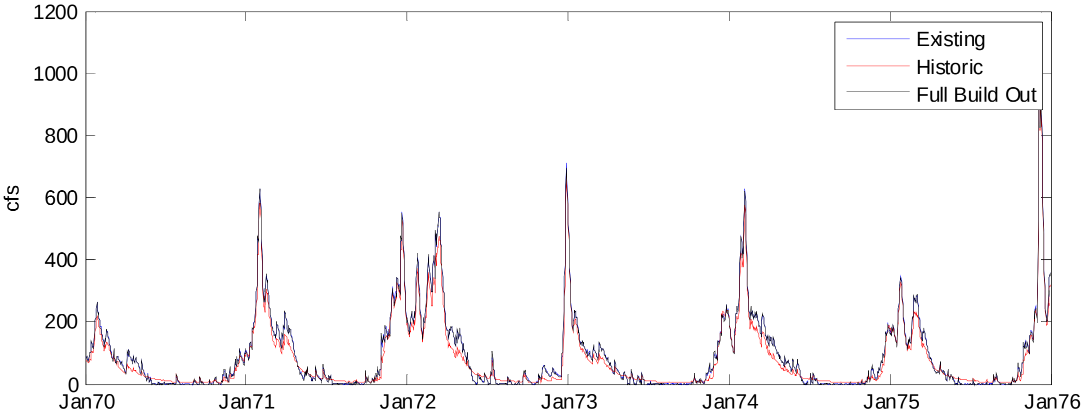


Figure 35. Simulated Historic, Existing and Full Buildout Bertrand Creek Streamflow (ProjNodeID=515)

Table 5 presents the portions of the water management input files for Bertrand Creek. This shows that there are four users simulated. For Existing conditions, self supplied residential supplies 3149 people at 0.3785 m^3/day (100 gal/day) for a maximum demand of 1191 m^3/day which amounts to 0.5 cfs. This is taken entirely from groundwater and varies seasonally according to the monthly demand fraction specified in MonthlyDemandFraction.txt at the bottom of Table 5. For Full Buildout conditions, the self supplied residential demand for 4687 people amounts to 0.75 cfs. The commercial, industrial, and transportation demands under Existing conditions are 13/4 m^3/day/acre for 145 acres to total 1943 m^3/day or 0.79 cfs. For Full Buildout conditions, this increases to a demand of 4.1 cfs. Dairy demands similarly come out at 0.35 cfs. Irrigation demands over the irrigated area are time varying and depend on the simulations of soil moisture.

Table 5. Water Management Tables for Bertrand Creek

Existing Conditions User.txt

UserId	User Type	POU_ID	Demand Vble	Demand Rate	InYear Demand Type	Return FlowID	Source MixingId	Num Sources	Source ID1	Source ID2	UserType
166	5	6	3149	0.3785	1	1	0	1	259	0	Self Supplied Residential
287	5	6	145	13.4	2	2	1	2	259	87	Self Supplied CIT
431	1	6	3.69E+07	0.004	5	-1	3	2	259	87	Irrigation
496	6	6	11368	0.0757	3	3	2	2	259	87	Dairy

Full Build Out Conditions User.txt

UserId	User Type	POU_ID	Demand Vble	Demand Rate	InYear Demand Type	Return FlowID	Source MixingId	Num Sources	Source ID1	Source ID2	UserType
171	5	6	4687	0.3785	1	1	0	1	259	0	Self Supplied Residential
294	5	6	759	13.4	2	2	1	2	259	87	Self Supplied CIT
446	1	6	3.79E+07	0.004	5	-1	3	2	259	87	Irrigation
515	6	6	11368	0.0757	3	3	2	2	259	87	Dairy

Source.txt

SourceID	Type	Source Location ID	Physical DailyMax	Physical AnnMax
87	1	6	1.00E+20	1.00E+20
259	2	6	1.00E+20	1.00E+20

ReturnFlow.txt

Return FlowID	Num Return Flows	Return Flow Units	Return Flow Amt1	Return Flow Type1	Return Flow Locn1	Return Flow WWTPID1
1	1	1	0.05	2	0	0
2	1	1	0.1	2	0	0
3	1	1	0.1	2	0	0

SourceMixing.txt

Source MixingID	Users Source Num	Units	Amount	Season Number	Seasons DefnID
1	1	1	0.2	1	1
1	2	1	0.8	1	1
2	1	1	0.2	1	1
2	2	1	0.8	1	1
3	1	1	0.7	1	1
3	2	1	0.3	1	1

MonthlyDemandFraction.txt

InYear Demand Type	Month1	Month2	Month3	Month4	Month5	Month6	Month7	Month8	Month9	Month10	Month11	Month12
1	0.8	0.8	0.8	0.7	1	1	1	1	0.7	0.8	0.8	0.8
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0.25	0.5	0.75	1	1	0.5	0	0	0

Table 6 gives the water balance for Bertrand Creek (Drainage 6, ProjNodeID=515) as calculated by the model for the four scenarios for the period 10/1/1960 to 9/30/2005. The top half of this table expresses all quantities in inches of water over the area of the drainage. The bottom half of this table expresses all quantities in cfs and provides information on simulated withdrawals for each user, as well as the return flows calculated. The area of Bertrand Creek drainage is 108.7 x 10^6 m^2 (26900 acres) so 1 inch per year is equivalent to 3.09 cfs. The return flows are calculated based on the return flow factors given in ReturnFlow.txt (Table 5).

Table 6. Bertrand Water Balance: 1961-2005.

Annual inches of water over area of drainage	Historic	Existing NWM	Existing	Full Buildout
(1) Precipitation	57.87	57.87	57.87	57.87
(2) Evapotranspiration	33.49	26.08	29.26	28.47
(3) Streamflow (drainage outlet)	24.37	31.79	28.17	27.94
(4) Baseflow (included in streamflow)	21.2	24.7	22.7	22.4
(5) Irrigation Withdrawals	0.00	0.00	5.80	5.71
(6) Non Irrigation Withdrawals			0.49	1.62
(7) Return flows			0.04	0.15
Closure (1)-(2)-(3)-(6)+(7)	0.01	-0.01	-0.02	-0.01
Flow Rate (cfs)				
Streamflow	75.32	98.24	87.06	86.33
Self Supplied Residential			0.41	0.62
Self Supplied Commercial, Industrial and Transportation			0.79	4.11
Irrigation			17.92	17.63
Dairy			0.30	0.29
Return Flows			0.13	0.47

Under Historic conditions the annual precipitation of 57.9 inches is simulated to be distributed as 24.4 inches to streamflow, and 33.5 inches to evapotranspiration. Under Existing LULC and artificial drainage conditions, but without water management (Existing NWM), the precipitation is simulated to be distributed as 31.8 inches to streamflow and 26.1 inches to evapotranspiration. The artificial drainage and changes in land use and land cover result in an increase in streamflow; however, much of this is in spikes of quick runoff following rainfall. Under Existing and Full Buildout conditions, irrigation withdrawals dominate the uses; however, non-irrigation uses do increase going to Full Buildout conditions, most notably the commercial, industrial, and transportation use. This is because of the way the model calculates this demand based upon LULC class area and the increase in this LULC class. In the Existing conditions simulation, we see that the precipitation is simulated to go as 29.3 inches to evapotranspiration, 28.1 inches to streamflow and 0.45 inches to consumptive use (non-irrigation withdrawals minus return flows) by non-irrigation users. In the Full Buildout simulation, the precipitation is simulated to go as 28.5 inches to evapotranspiration, 27.9 inches to streamflow and 1.5 inches to consumptive use by non-irrigation users.

Note that the mass balance closure is calculated as (1) Precipitation minus (2) Evapotranspiration minus (3) Streamflow minus (6) Non-irrigation withdrawals plus (7) Return flows. The irrigation withdrawals do not factor into this mass balance because they take water out of either the stream or groundwater within the drainage and then apply it like rainfall in the same drainage, thus not actually removing it from the drainage. This is not always the case because sometimes irrigation would have its source in another drainage. The irrigation withdrawals are taken 70% from groundwater and 30% from streamflow as indicated in the SourceMixing.txt table (Table 5). The consumptive use by irrigation gets simulated in the calculations of evapotranspiration, which Table 6 indicates are higher for the Existing simulation than Existing NWM simulation, reflecting the extra evapotranspiration of irrigated water. Baseflow also does not factor in the mass balance because the baseflow is included in the total streamflow amount. In TOPNET simulations, baseflow is designated as the outflow from the groundwater saturated zone store. Without a comprehensive groundwater model, this is the model approximation of groundwater discharge. The model keeps track of the water content of the groundwater saturated zone store, soil store and the vegetation canopy. However, over this 45 year simulation period, the difference in beginning and ending values of these stores was negligible compared to the fluxes simulated, so they are not reported. Evaporation from intercepted water held in the vegetation canopy is included in the evapotranspiration total given in Table 6.

Conclusions

Four input scenarios: (1) Historic conditions, (2) Existing conditions without water management, (3) Existing conditions with water management and (4) Full Buildout conditions were run on the TOPNET surface water quantity for WRIA 1. Differences in land use and population between these scenarios drove differences in water demand. A number of comparisons of model results from these scenario runs were presented. The first set of comparisons between Historic and Existing conditions without water management illustrated the sensitivity of the model hydrology to vegetation and artificial drainage. The second set of comparisons between the Existing without water management and Existing conditions scenarios isolated the impact of direct water management on streamflow. Although the Existing without management scenario is implausible, it is illustrative here in demonstrating the capability of the model to represent management alternatives. This set of comparisons showed that the Middle Fork diversion has minimal impact on the main stem flow in the Nooksack River, but a large impact on the input to Lake Whatcom. The third set of comparisons examined the difference between Existing and Full Buildout conditions. Significant increases in demand upon Lake Whatcom were illustrated. Finally, the fourth set of comparisons examined Historic, Existing and Full Buildout simulations in the overall Nooksack River basin as well as smaller Bertrand Creek and Deer Creek. At the scale of the Nooksack River basin, Full Buildout is simulated to have minimal impact on the streamflow. However, at the scale of Bertrand and Deer Creek there are times of the year when streamflow is reduced to zero due to the simulation of demands.

The comparisons presented have validated the key aspects of the model’s ability to simulate streamflow from rainfall and properly model water management impacts based on user inputs. However, it should be noted that there are significant simplifying assumptions in the way the model represents the physical processes and in the way user demand inputs were derived. Any decisions based on these results need to understand and appreciate the limitations of these assumptions.

References

Collins, B. D. and A. J. Sheikh, (2004), "Historical Riverine Dynamics and Habitats of the Nooksack River," Final Project Report to the Nooksack Indian Tribe, Natural Resources Department, Deming, WA, http://riverhistory.ess.washington.edu/project_reports/screen_nooksack_081204.pdf.

Contents of Electronic Appendix

File	**Description**
population_data.xls	Table of population by drainage used in deriving user demands for Existing conditions (2000) and Full Buildout conditions (2022)
Bertrand_Exceedance.xls	Spreadsheet giving complete Exceedance analysis data for Bertrand Creek.