Runoff and Nonpoint Sources Control using LID for the Boise River Watershed, Idaho

Jae Ryu, Ph.D., PE and Jungjin Kim

Respectively, Assistant Professor and Graduate Research Assistant
Department of Biological & Agricultural Engineering, University of Idaho
Idaho Water Center
322 E Front St.
Boise, ID 83702
Email: jryu@uidaho.edu

Introduction

The urbanization contributes to promoting land use changes from pervious condition to impervious land. The impervious land, however, affects watershed hydrology and water quality standard in waterways due to abrupt runoff patterns and nonpoint source (NPS) from the altered landscape. In this study, low impact development (LID) techniques are applied to evaluate how LID applications can mitigate flash flood and improve water quality at the rural-urban interface, such as Boise River Watershed. The hydrological simulation program-Fortran (HSPF) is utilized to evaluate how LID approaches can improve flood mitigation and water quality in the study area. The results show that bioretention as a LID application can reduce flood potential and improve water quality at the Boise River Watershed.

Study area

The Boise River Watershed (BRW) is 11,000 km^2 with a main stem length of 164 km (**Fig. 1**). As a tributary of the Snake River Watershed, the BRW plays a key role of providing water supply, which is lifeblood of Treasure Valley - agriculture dominated areas. Major cities including Boise, Nampa, Meridian, and Caldwell are situated within this watershed. The characteristics of the BRW are that more than 40 percent of Idaho residents live in this watershed and 60 percent of people are residing around the floodplain. Flood has occurred repeatedly over time due to climate variability as well as other physical changes, such as land development. Therefore, experts of emergency management often indicate that potential flood risks shouldn't be deemphasized in this area (Kelly, 2014). Additionally, water quality issues driven by urbanization associated with land use change are also highlighted at water research and political agenda.

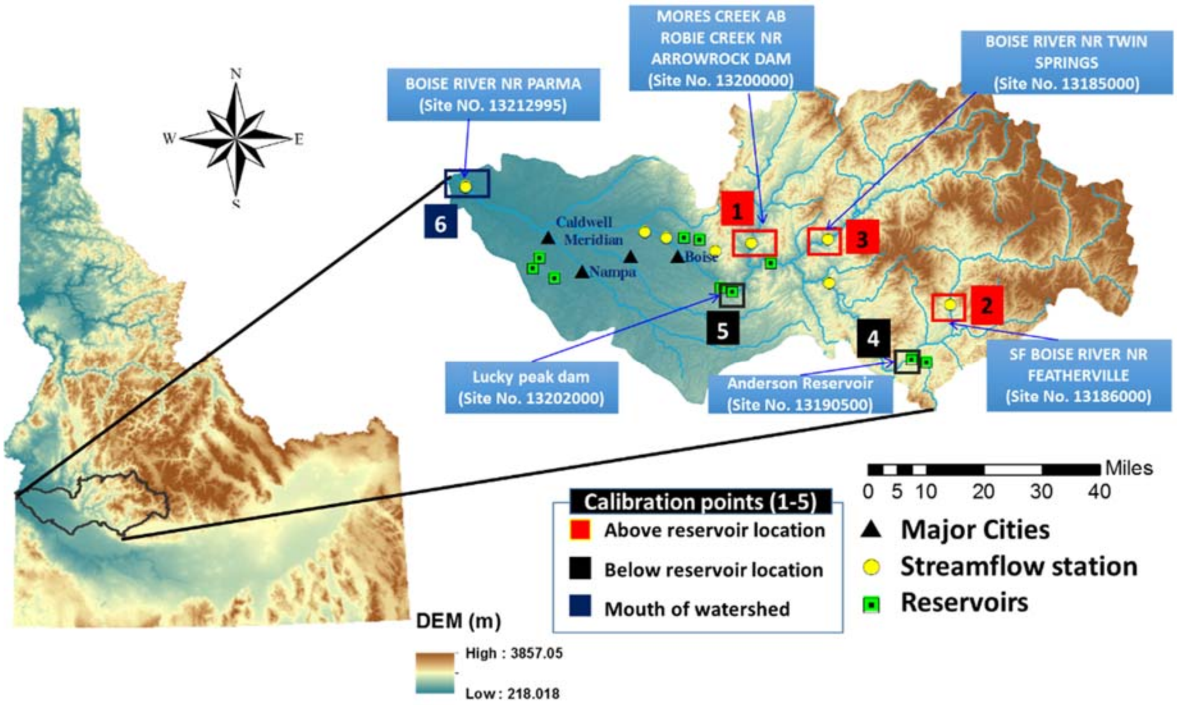

Fig.1. Map of the Boise River Watershed.

Data use and processes

To simulate streamflow and nutrient load using HSPF model, precipitation, temperature, wind speed, solar radiation, and potential evapotranspiration (PET) data are used. Precipitation, temperature, and solar radiation data were obtained from the gridded high-quality metrological data developed by Abatzoglou (2012). These dataset have 4 km by 4km resolution and daily time steps from 1979 to 2013. For the PET, Jensen's method is typically used in HSPF, but Penman-Monteith method (Monteith, 1965) was used in this study because previous studies indicate its outperformances against other PET methods (Jensen et al., 1990; Chiew et al., 1995). Also, Penman-Monteith's approach is recommended by FAO as standard method for computing PET. For model calibration, observed streamflow data were obtained from six USGS streamflow gauge stations as shown in **Fig. 1**. Note that calibration target points 1, 2, and 3 are located above reservoirs so that upstream diversion is considered negligible, while calibration target points, 4, 5, and 6 are located below reservoirs where streamflow is likely affected by the reservoir release.

To parameterize channel, soil, and land use profiles, watershed delineation processes were carried out using a series of GIS dataset, such as Digital Elevation Model (DEM) obtained from the National Weather Service in 30m by 30m resolution. For the land use data, two different land use year for 1992 and 2006 are used to identify how land use change can affect hydrological variation in stream channel and also how urbanization can contribute to water quality in the Boise River. To incorporate land use information into hydrological and water quality simulations, we simplify land use classification to seven land use categories, including urban area, barren, forest, upland, grass, agriculture, and wetland. **Fig. 2** and **Table 1** represent geospatial land use information and classification, respectively.

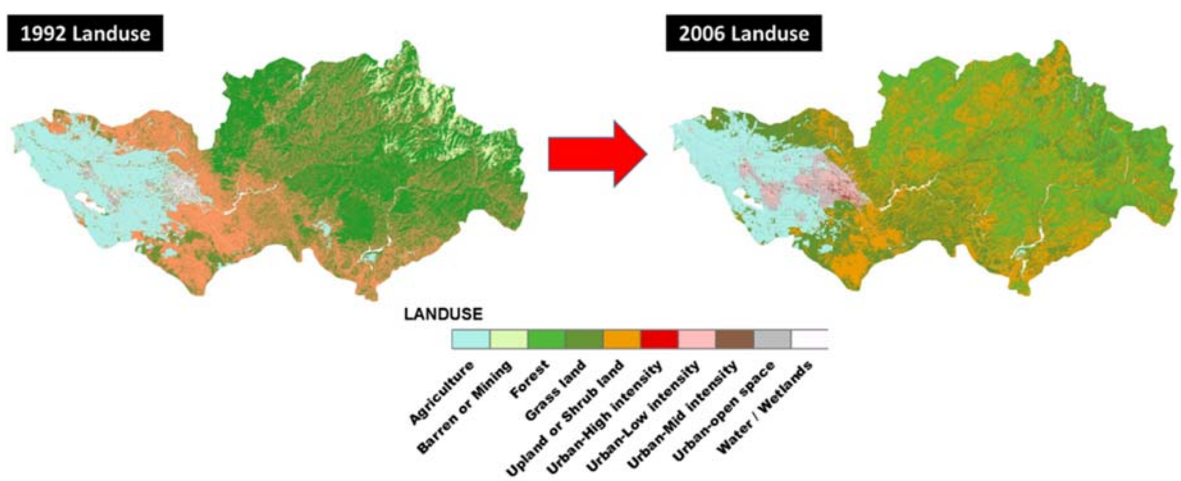

Fig. 2. Land use change from 1992 to 2006 in the Boise River Watershed.

Model calibration

BeoPEST software was used to calibrate HSPF from January 1, 2000 to September 31, 2013. BeoPEST developed by Hunt et al (2010) is an automatic calibration tool and special version of efficient parallel-enabled model calibration using PEST. BeoPEST uses Gauss-Marquardt-Levenberg (GML) method to minimize systematic error between the observed and simulated flows using TCP/MPI parallel-mode based on command line switches (Hunt et al, 2010). The strength of BeoPEST is to reduce calibration time and workload. It can be also employed with many calibration parameters since it can accommodate hundreds or thousands of slaves serving a single master during calibration.

Table 1. The land use classification for 1992 and 2006 at the study area.

land use	Land use (km^2)		Land use change	
	1992	2006	(km^2)	(%)
Urban area	215.02	547.03	332.01	154.41
Barren or Mining	391.11	22.61	-368.50	-94.22
Forest	3055.39	3009.51	-48.88	-1.50
Upland or Shrub land	3121.04	3032.26	-88.78	-2.84
Grass land	2041.93	2423.62	381.69	18.69
Agriculture	1492.43	1293.62	-198.80	-13.22
Water / Wetlands	121.87	110.13	-11.74	-9.63

Bioretention

For an application of LID, bioretention was employed to evaluate how land use change affects hydrology and river environment by considering 50% of entire urban area implemented based on 2006 land use condition. Since bioretention is a depressed landscape area, it can reduce runoffs significantly through infiltration processes. Consequently, it can delay overland flow directly discharged to waterways so that potential risks of flood and soil erosion can be mitigated. Note that bioretnetion is widely used across the states due to its flexibility and scalability.

Results

Hydrological statistics, such as correlation coefficient (R) and Nash-Sutcliffe coefficient (NS) are computed to evaluate how well HSPF simulates streamflow. **Table 2** shows the statistical results of HSPF model at six calibration target points in BRW over the study period from January 1. 2000 to September 30. 2013. Calibration points 1, 2, and 3 show that higher R = 0.88 – 0.89 and NS = 0.75 – 79 values, while calibration target points 4, 5, and 6 show less values, R = 0.70 – 0.77

and NS= 0.42 - 0.54. Perhaps, anthropogenic activities, such as canal diversion, stream withdrawal, irrigation return flow below reservoirs infuse additional uncertainty into hydrological simulations. However, in general, HSPF simulates streamflow quite well based on R and NS values after model calibration in BRW (See Table 2).

Table 2. The R and NS values after HSPF model calibration at calibration target points, 1 thru 6 during January 1. 2000 – September 30, 2013

	Above Reservoirs			Below Reservoirs		Mouth of watershed
	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
R	0.89	0.88	0.88	0.71	0.77	0.70
NS	0.79	0.75	0.77	0.42	0.54	0.48

Fig. 3 shows hydrograph comparisons for the calibrated and observed streamflow results at calibration target points from 1 to 6. At calibration target points 1, 2, and 3, the simulated streamflow results match well with the observed streamflow for high and low flow conditions. Also, at calibration target point 4 and 5, the simulated streamflow result fairly reflect the observed stremflow by incorporating reservoir release into HSPF modeling framework. However, at calibration target point 6, which is mouth of the watershed, the simulated low flow shows somewhat different from that of the observed flows. Since this incident is induced by many water diversion activities near calibration target point 6, additional data, water network information, and more computational effort are required to improve model performances.

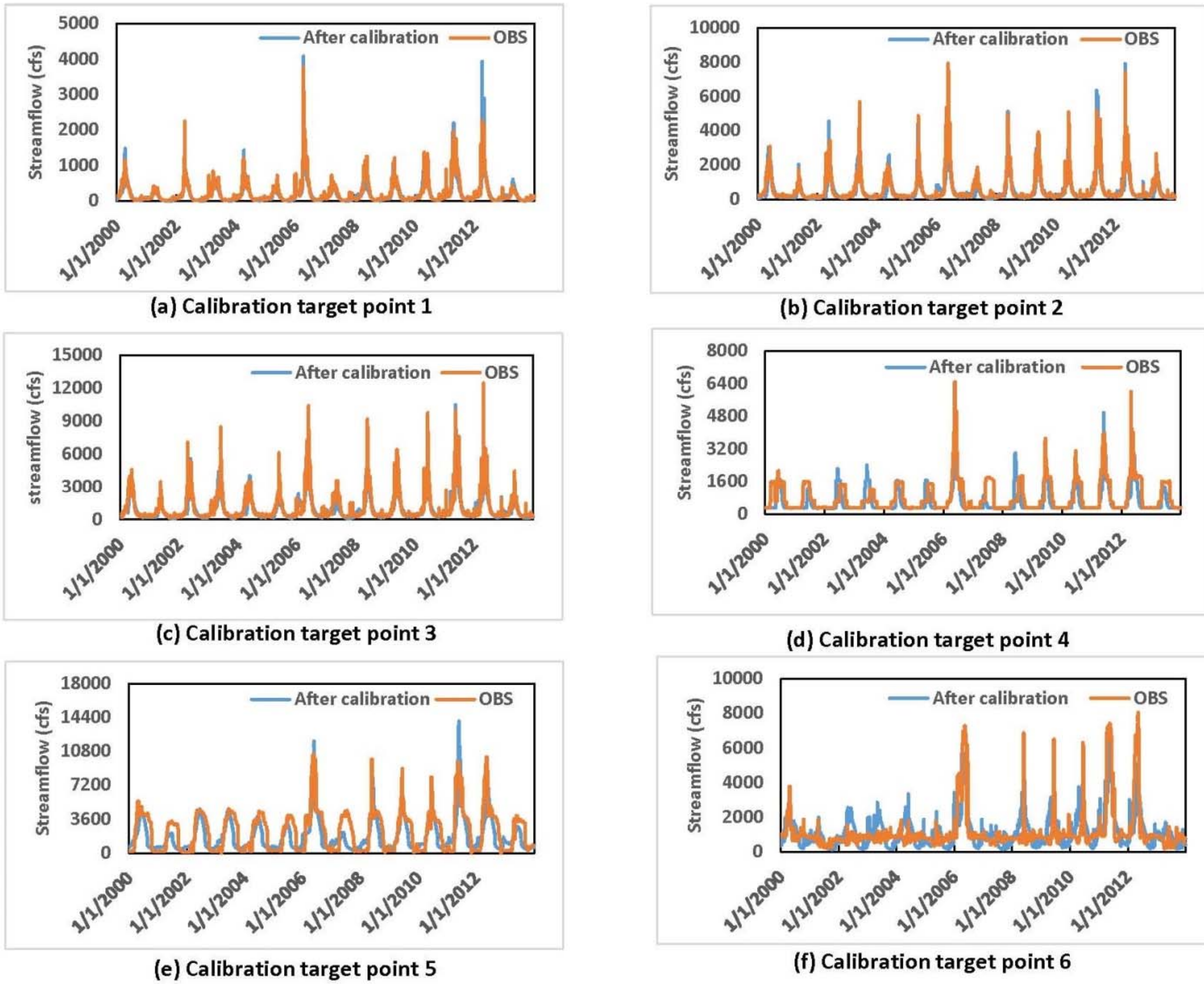

Fig. 3. Hydrograph of the simulated and observed streamflow at calibrated target points, 1 thru 6.

Table 3 and 4 show the results of the simulated streamflow and NPS load, including BOD, T-N, and T-P. **Table 3** shows that the simulated monthly streamflow results associated with land use change with/without LID applications. When 2006 land use is employed without LID, the simulated streamflow increases by 28 % in average as opposed to that from 1992 land use condition. But, when bioretention is implemented in the urban area in 2006 land use condition, the streamflow decreases by 6 % in average. This implies that bioretention can mitigate flood impacts in the study area.

Table 3. The simulated monthly streamflow results associated with land use change with/without LID.

Month	Streamflow (cms)			Streamflow increase (%) from 1992 to 2006 land use condition	Streamflow decrease (%) with LID
	1992 Landuse	2006 Landuse without LID	2006 Landuse with LID		
1	22.82	26.66	24.05	17	11
2	25.23	29.51	26.85	17	10
3	36.60	45.47	40.04	24	14
4	53.68	61.60	58.46	15	5
5	73.58	91.87	89.57	25	3
6	54.18	73.61	72.21	35	1
7	33.74	41.83	41.47	24	1
8	18.59	26.82	26.63	44	1
9	9.55	14.73	14.34	54	3
10	7.64	9.94	9.35	30	6
11	10.53	13.41	12.01	27	12
12	16.72	20.64	18.42	23	12
Mean	30.24	37.97	36.12	28	6

Table 4. The simulated monthly NPS results with/ without LID associated with land use change at mouth of the watershed (calibration target point 6).

Month	BOD (kg/day)			T-P (kg/day)			T-N (kg/day)		
	1992 Land use	2006 land use w/o LID (%)#1	2006 land use with LID (%)#2	1992 Land use	2006 land use w/o LID (%)#1	2006 land use with LID (%)#2	1992 Land use	2006 land use w/o LID (%)#1	2006 land use with LID (%)#2
1	2,744	3,909 (42)	2,945 (33)	63	96 (52)	70 (38)	2,239	2,466 (10)	2,064 (19)
2	3,080	4,396 (43)	3,372 (30)	69	104 (52)	79 (32)	2,434	2,861 (18)	2,436 (17)
3	5,076	7,309 (44)	5,713 (28)	116	183 (58)	139 (32)	6,183	8,271 (34)	7,079 (17)
4	8,311	9,305 (12)	8,005 (16)	247	252 (2)	223 (13)	12,330	12,053 (-2)	10,686 (13)
5	9,579	10,521(10)	9,597 (10)	365	394 (8)	373 (6)	15,658	10,244 (-35)	9,400 (9)
6	5,852	6,734 (15)	6,355 (6)	207	255 (23)	247 (3)	10,990	6,047 (-45)	5,659 (7)
7	2,841	3,074 (8)	2,897 (6)	92	94 (3)	91 (4)	6,112	2,676 (-56)	2,514 (6)
8	1,164	1,580 (36)	1,464 (8)	35	46 (33)	44 (5)	2,871	1,381 (-52)	1,302 (6)
9	610	1,017 (67)	842 (21)	17	28 (66)	24 (17)	1,435	949 (-34)	848 (12)
10	573	945 (65)	699 (35)	16	26 (60)	20 (33)	1,216	965 (-21)	829 (16)
11	1,125	1,831 (63)	1,275 (44)	30	49 (64)	35 (42)	1,540	1,487 (-3)	1,227 (21)
12	2,011	2,949 (47)	2,156 (37)	46	71 (56)	51 (39)	1,941	1,996 (3)	1,668 (20)
Mean	3,580	4,464 (38)	3,776 (23)	108	133 (40)	116 (22)	5,412	4,283 (-15)	3,809 (14)

#1 Increasing of NPS load without LID from 1992 to 2006 land use.

#2 Decreasing of NPS load with LID in 2006 land use.

Table 4 indicates the simulated monthly NPS load affected by land use change along with LID applications. For the BOD and T-P load results, they are increased by 38 % and 40 % in average when 2006 land use is employed without LID, whereas that with LID applications is decreased by 23% and 22 % in average as opposed to the results from 1992 land use condition. T-N load result also shows that LID can improve water quality by decreasing T-N up to 15 % in average. But, it is inconclusive that such improvement of NPS control is solely driven by LID applications because agricultural areas from which NPS originate has been decreased by 13 % in 2006 since 1992 (See Table 1).

Conclusions

This research investigates how urbanization can affect the hydrological variation of streamflow and water quality driven by NPS at the Boise River Watershed. An application of bioretention as LID was evaluated to verify how LID can contribute to mitigating flood impacts as well as environmental risks associated with water quality. An advanced parallel-enabled calibration approach using BeoPEST was used to calibrate HSPF model at several calibration target points, including above, below, and at mouth of the watershed. Based on R and NS values, the results show that overall performance of HSPF are reasonably good, but additional works are required to tune the model for better low flow simulations. Since somewhat poor modeling results are observed at calibration target point 6, which is mouth of the watershed, additional information, such as irrigation data is needed to minimize uncertainty induced by anthropogenic activities within model calibration frameworks.

After investigating the variation of streamflow and water quality components, including BOD, T-P, and T-N using bioretention as LID, we conclude that LID would be promising to mitigate flood risks and to improve water quality in the study area. Thus, when 2006 land use information was employed, both hydrological and environmental benefits are achieved. For example, streamflow decreased by 6% while concentrations of BOD, T-P, and T-N decreased by 23%, 14%, and 22% in average, respectively when bioretention was implemented along with 2006 land use condition.

In closing, bioretention as LID in the urban area is beneficial to mitigate hydrological and environmental impacts in the sense that it can reduce flood potential and improve water quality. But, additional future work is required to investigate how the main effect and joint effect of multiple LID applications and/or urbanization (land use change) can address water quantity and quality issues in which many states are currently facing. Such efforts will convince local stakeholders to promote LID opportunities by pursuing risk-free communities in the future. The cost-benefit analysis will be another avenue to assess the feasibility of many LID options in objective manner rather than political influence, which is typically determined by personal preference.

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