Appendix H – Basin-Wide Hydrologic Alteration Assessment

Contents

The Middle Potomac River Watershed Assessment included a basin-wide assessment of hydrologic alteration. The purpose of this assessment was to understand the watershed drivers of hydrologic alteration (land uses, water uses, and meteorological conditions). This appendix describes in detail the methodology, sources, magnitude, and spatial extent of hydrologic alteration under current and future conditions in the study area, and the assessment results. It also provides an Excel file of the data and graphs used in the comparison of observed and simulated flow metrics plotted against different land uses and shown in Figures 10 and 11 of this document.

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Document (PDF file)

- AppendixH_FlowAlterationAssessment.pdf – this file

Data file (Excel 2007 spreadsheet)

- FlowAlt-vs-LandWater.xlsx

Introduction

One purpose of this report is to describe the hydrologic alteration from water and land uses in the study area. The WOOOMM hydrologic effort, described in Appendix E, produced a daily flow time series for baseline and current scenarios for the 747 ELOHA watersheds. Baseline and current flow metrics calculated from the time series were coupled with biological data to develop the flow alteration – ecological response relationships. As a reminder, the baseline scenario is estimating flows that have minimal anthropogenic influence. In the baseline scenario, there are no simulated withdrawals, discharges, or impoundments and land uses are greater than or equal to 78 percent forest and less than or equal to 0.35 percent impervious cover. The current scenario takes a snapshot of present-day withdrawals, discharges, impoundments, and land use conditions and simulates this over a 21-year observed meteorological history. The simulated daily flow time series were utilized in the estimation of a number of flow metrics. Differences in a particular flow metric between current and baseline scenarios indicate an amount of hydrologic alteration in a particular watershed. Specifically, comparisons of baseline and current scenario flow metric values indicate the amount of hydrologic alteration that exists in a watershed under current conditions when compared to pre-anthropogenic influence.

Hydrologic alteration estimated between baseline and current conditions as part of this study can only be the result of a handful of driving forces; namely, land use, surface withdrawals, discharges, and impoundments. Although hydrologic alteration can, in reality, be caused by these and other factors, these are the watershed characteristics that are adjusted within the model and are driving alteration in the simulated flows. This report documents the spatial distribution of the changes in these inputs and connects changes in these watershed characteristics with flow alteration.

Spatial Distribution of Model Simulated Watershed Characteristics

Water Uses

Water uses represented in the hydrologic model include impoundments, surface withdrawals, and discharges.

Impoundments The majority of the ELOHA watersheds have no simulated impoundments, withdrawals, or discharges (Figure 1). 481 impoundments were identified in the National Inventory of Dams (NID) in the Potomac basin. Of these, 16 were included in the hydrologic model current scenarios (see Appendix E). The locations of the modeled impoundments are shown in Figure 2. Only 15 of the 747 ELOHA watersheds contain impounded waters. Only 6 of those watersheds have greater than 20 percent of the normal storage capacity of median flow volume at the watershed outlet. These watersheds include those on Rocky Gap Run, Little Seneca Creek, Dry Seneca Creek, two on Evitts Creek, and Savage River. The maximum percent impounded normal storage volume as a function of median annual flow volume is 162.1 percent on Rocky Gap Run. The relatively low sample size is a limitation in the statistical analysis of hydrologic alteration from impoundments, as described in the hydrologic alteration section of this document.

Withdrawals There are 942 withdrawal locations in the model simulated area (Figure 2, light yellow dots). Of these, 253 surface withdrawals are included in the hydrologic model. Figure 3 shows the locations of the surface withdrawals in blue dots. The magnitude of the withdrawal, as defined in the current model scenario, is indicated by the size of the dot. 115 of the 747 ELOHA watersheds have some amount of withdrawal. Of these, only 5 have withdrawal totals that are greater than 20% of the median annual flow. These 5 watersheds are associated with Rocky Gap Run-Evitts Creek, Conococheague Creek, Little Hunting Creek, Evitts Creeks, and Tuscarora Creek. The maximum percent withdrawal as a function of median annual flow is 396.4 percent in the Conococheague watershed.

Discharges A total of 227 discharges are contained in the discharge database, however, only 143 were simulated in the current scenario because that is the number in operation as of 2005 (the year used for the snapshot of current discharges) (Figure 4). 82 watersheds have some amount of discharges, 5 of which have discharges greater than 20 percent of the median annual flow. The maximum percent discharge as a function of median annual flow is 101.5 percent on Eagle Run in West Virginia.

Land Uses

Land uses are not spatially explicit within the HSPF model or WOOOMM and are represented in tabular format by watershed. The ranges of land uses for urban, impervious cover, forest, and agriculture in the Middle Potomac study area are shown in Figure 1. Four urban land use categories (high intensity pervious urban, low intensity pervious urban, high intensity impervious urban, and low intensity impervious urban) are utilized to calculate the percent urban of the total watershed area. Amongst the 747 ELOHA watersheds, the amount of urban area ranges from 0 to 93 percent in the current scenario, with a median value of 5 percent. A sub-set of the urban land use categories (high intensity impervious urban and low intensity impervious urban) are utilized in the calculation of percent impervious cover. In the current scenario, impervious cover ranges from 0 to 24.4 percent. Percent forest is a combination of two land use categories (forest and harvested forest). The Potomac is a relatively forested basin, with percent forest ranging from 7 to 100 percent for the 747 ELOHA watersheds in the current scenario, with a median value of 71 percent. Percent agriculture is calculated as a function of 16 land use categories, as described in the CBP HSPF model's Phase 5.2 land use classification. Agriculture ranges from 0 to 81 percent for watersheds in the current scenario, with a median value of 18 percent.

The majority of the basin shows a slight increase (0.1 to 15 percent) in urban areas between baseline and current conditions. The largest increases are in the DC metropolitan area and extending up into the Monocacy and Antietam watersheds, with a handful of other hotspots throughout the basin including the Blacks Run watershed in Harrisonburg, VA. Very few watersheds show a decrease in urban areas between baseline and current scenarios, with a maximum decrease of 2.8 percent. Change in impervious cover between the baseline and current scenarios is related to the change in urban areas, however, it is slightly different in that not all urban areas are impervious. The spatial distribution of changes in impervious cover is shown in Figure 6.

Between the baseline and current scenarios, much of the basin decreased the amount of forest cover. This is because the definition of baseline conditions calls for greater than or equal to 78 percent forest. Under existing conditions, many watersheds have less than 78 percent forest due to the urban and agricultural land uses that have built up with increases in anthropogenic activity in the watersheds. A decrease in forest in the Monocacy, Antietam, Conococheague, and Shenandoah watersheds are associated with an increase in agricultural areas (Figure 7 and Figure 8). The DC metro area shows a large decrease in forest associated with an increase in urban areas (Figures 5-7). The rest of the basin shows a slight decrease in forest associated with increases in urban and agriculture, depending on the specifics of the watershed.

In summary, the ELOHA watersheds include a range of land use conditions represented by percent forest, agriculture, urban, and impervious cover. On the other hand, the majority of the 747 watersheds have no modeled influence of impoundments, withdrawals, and discharges.

Hydrologic Alteration: Baseline and Current Scenarios

The modeled watershed characteristics described in the previous section drive the alteration in flow metrics between model scenarios. A comparison of baseline and current scenario flow metrics reveals alteration that has occurred between the time that the watershed was least-impacted by anthropogenic influences and present-day conditions. Figure 9 is one illustration of land use effects on flow metrics, specifically high pulse count, flood free season, low pulse duration, and flashiness. Increasingly positive alteration in flashiness is associated with an increase in urban areas. Increasing alteration in a negative direction in flood free season is also associated with an increase in urban areas.

Another graphical approach for examining associations between anthropogenic disturbance and flow alteration is shown in the series of graphs in Figure 10. In these graphs, each flow metric is plotted against three general land uses: forest, agriculture, and urban. Watersheds with a predominant anthropogenic factor and low levels of other factors are indicated. For example, watersheds with relatively high impervious surface area (>10 percent) and no withdrawals, discharges, or impoundments and less than 6 percent agriculture are identified with red dots. Watersheds with high percentages of agriculture (>50 percent) and no withdrawals, discharges, or impoundments and less than 0.7 percent impervious surface area are indicated with brown dots. Watersheds with surface withdrawals greater than 65 percent of median flow in heavily forested (>75 percent) watersheds are identified with large yellow dots. Watersheds with impoundment storage capacity greater than 30 percent of median flow in heavily forested (>75 percent) watersheds are identified with large dark blue dots. Watersheds with the highest discharges (>20 percent of median flow) were always coincident with intense agriculture and/or urban land uses, so discharge impacts could not be isolated. However, they are plotted on the graphs as yellow triangles. Regressions through some of the data are indicated with dashed lines; regressions through all of the data are indicated with solid lines.

It is readily apparent in the graphs that urban area affects many more flow metrics than agricultural area and has much stronger associations with flow alteration. Forest loss is essentially a mirror of urban impacts with alteration increasing as forest declines. Table 4 summarizes the changes in flow due to urban and agriculture and, in as much as is possible to discern, withdrawals, discharges, and impoundments.

A second set of graphs applies the same color-coding approach to identify specific watersheds but plots the data points against percent impervious surface (Figure 11). Percent imperviousness is very closely related to percent urban however the relationship is not 1-to-1 and can be changed by management actions. The graphs show many highly correlated relationships between flow metric alteration and percent impervious surface, with clear breakpoints above which flow alteration increases. Those breakpoints occur in a narrow range between 0.3 percent and 1.0 percent impervious surface. Flow metrics are not significant or noticeably altered by impervious surface area below this level.

As previously noted, the impacts of withdrawals and impoundments on flow alteration are somewhat more difficult to evaluate due to the limited sample size, particularly for impoundments. An evaluation was undertaken to understand whether there was a significant relationship between changes in flow metrics between the current and baseline scenarios and the amount of impounded and withdrawn water. Looking only at watersheds with some amount of impounded water (n=15), the amount of impounded water in relation to median flow volume is not statistically significant at the 0.01 or 0.05 level for any of the selected flow metrics (Table 1). For this same sub-set of watersheds, however, withdrawals and impervious cover are significantly correlated at the 0.01 level with alteration in numerous flow metrics. Specifically, withdrawals are significantly correlated to median flow, August median flow, and low pulse count. Impervious cover is significantly correlated to alteration in a number of flow metrics in these watersheds with impounded waters including MH21, high pulse count, flashiness, low pulse duration, 3-day maximum, rise rate, and high flow frequency.

A sub-set of the 15 watersheds, those with greater than 9.48 percent impounded water of median annual flow volume, were also evaluated. These 6 watersheds were selected because 9.48 percent impoundment was identified as a high impoundment threshold in the CART analysis (Appendix E). Alteration in selected flow metrics is not significantly correlated to the amount of impoundments in these watersheds (Table 2).

To evaluate the influence of withdrawals on the alteration in selected flow metrics, a sub-set of watersheds (those with some amount of withdrawals) were evaluated. In watersheds with withdrawals (n=115), the seasonal Q85 is significantly correlated with the amount of impounded water; although the amount of impounded water only explains 12 percent of the variability in the flow metric. Withdrawals are significantly correlated with a number of flow metrics including MH21, DH17, median flow, August median, fall rate, seasonal Q85, low and pulse count. For all of these metrics, the amount of withdrawals explains less than 25 percent of the variability in flow metric alteration. In the same sub-set of watersheds, percent impervious cover is significantly correlated with all selected flow metrics except median flow, and seasonal Q85.

Discussion

Overall, hydrologic alteration in the study area appears to be driven by land uses, primarily the percent of impervious cover. Withdrawals are also correlated with hydrologic alteration, in primarily mid and low range flow metrics. Impoundments in the Potomac basin are associated with limited hydrologic alteration. This is likely due to the relatively small number of modeled impoundments and the relatively small number of watersheds that include those impoundments.

Additional efforts would complement and enhance this understanding of the sources of hydrologic alteration across the Potomac basin. In particular, the effects of withdrawals would be better understood with the inclusion of groundwater withdrawals in the model simulation. Current modeling efforts do not include groundwater withdrawals due to limitations in the model and in the available data. In addition, understanding of the hydrologic impact of impoundments is limited in this study due to the fact that only 15 of the Potomac ELOHA watersheds contain impoundments. Therefore, the amounts of hydrologic alteration resulting from this analysis more likely result from the specifics of the few modeled impoundments rather than an understanding of the hydrologic alteration associated with impoundments in general. Inclusion of additional impoundments in the Potomac basin could address this issue by increasing the sample size. Alternatively, selection of additional watersheds that include the currently modeled impoundments would enhance our understanding of the hydrologic and biologic impact of these impoundments.

Table 1. For watersheds with some impounded water (n=15), relationships of flow alteration in select flow metrics to impoundments, withdrawals, and impervious cover. Relationships with a p value less than or equal to 0.01 are highlighted in green.

	% Impoundment of Median Flow @ WS Outlet		% Withdrawal of Median Flow @ WS Outlet		% Watershed Impervious Cover	
Flow Metric	R^2	P value	R^2	P value	R^2	P value
High flow index, MH21	0.16	0.14	0.09	0.27	0.60	0.00
High flow duration, DH17	0.23	0.07	0.14	0.17	0.32	0.03
High pulse count	0.00	0.81	0.09	0.28	0.64	0.00
High pulse duration	0.05	0.41	0.02	0.59	0.27	0.05
Median	0.03	0.52	0.72	0.00	0.19	0.11
August median	0.04	0.48	0.51	0.00	0.00	0.90
Fall rate	0.00	0.91	0.05	0.43	0.01	0.69
Flashiness	0.08	0.32	0.06	0.36	0.74	0.00
Q85Seas	0.01	0.79	0.10	0.24	0.00	0.95
Low pulse duration	0.01	0.73	0.08	0.32	0.43	0.01
Low pulse count	0.13	0.18	0.39	0.01	0.00	0.95
3-day maximum	0.00	0.92	0.09	0.28	0.72	0.00
7Q10	0.01	0.71	0.04	0.48	0.00	0.96
Rise rate	0.02	0.62	0.00	0.94	0.75	0.00
High flow frequency	0.01	0.67	0.12	0.21	0.71	0.00

Table 2. For watersheds with greater than 9.48% impounded water of median annual flow volume, relationships of flow alteration in select flow metrics to percent impoundment of median annual flow volume (n=6).

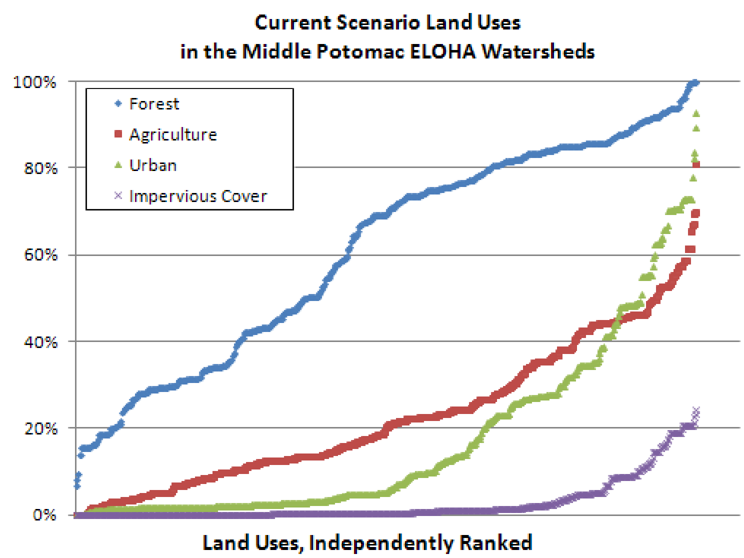
	% Impoundment of Median Flow @ WS Outlet	
Flow Metric	R^2	P value
High flow index, MH21	0.02	0.75
High flow duration, DH17	0.05	0.62
High pulse count	0.02	0.74
High pulse duration	0.01	0.86
Median	0.00	0.89
August median	0.01	0.83
Fall rate	0.17	0.35
Flashiness	0.01	0.84
Q85Seas	0.04	0.65
Low pulse duration	0.07	0.57
Low pulse count	0.03	0.73
3-day maximum	0.01	0.82
7Q10	0.02	0.81
Rise rate	0.03	0.71
High flow frequency	0.00	0.96

Table 3. For watersheds with greater than zero surface withdrawals (n=115), relationships of flow alteration in select flow metrics to impoundments, withdrawals, and impervious cover. Relationships with a p value less than or equal to 0.01 are highlighted in green.

	% Impoundment of Median Flow @ WS Outlet		% Withdrawal of Median Flow @ WS Outlet		% Watershed Impervious Cover	
Flow Metric	R^2	P value	R^2	P value	R^2	P value
High flow magnitude, MH17	0.00	0.99	0.06	0.01	0.23	0.00
High flow duration, DH17	0.00	0.60	0.06	0.01	0.45	0.00
High pulse count	0.00	0.67	0.00	0.67	0.46	0.00
High pulse duration	0.00	0.69	0.03	0.06	0.29	0.00
Median	0.03	0.06	0.24	0.00	0.03	0.07
August median	0.00	0.67	0.18	0.00	0.09	0.00
Fall rate	0.08	0.00	0.08	0.00	0.17	0.00
Flashiness	0.00	0.64	0.03	0.05	0.69	0.00
Q85Seas	0.12	0.00	0.07	0.01	0.03	0.05
Low pulse duration	0.00	0.97	0.01	0.36	0.26	0.00
Low pulse count	0.00	0.79	0.08	0.00	0.32	0.00
3-day maximum	0.00	0.51	0.00	0.83	0.72	0.00
Rise rate	0.00	0.69	0.00	0.80	0.64	0.00
High flow frequency	0.00	0.57	0.01	0.39	0.21	0.00

Table 4. A substantial increase in the indicated anthropogenic use changes the flow metric value in the following way: ▲, raises magnitude, rate of change, or frequency, or lengthens duration; △, slightly raises or lengthens flow metric; =, does not change flow metric; ▽, slightly lowers or shortens flow metric; ▼, lowers or shortens flow metric. No symbol indicates enough data were not available. See text for details.

	%Urban	%Agri-culture	%Impound-ments	%Dis-charges	%With-drawals
Magnitude					
3-day maximum	▲	▽	=		▽
annual mean	▲	=	▽	▲	▼
median	▽	=	▽	▲	▼
August median	▽	△		▲	▼
3-day minimum	=	▲		▲	▽
Change					
flashiness	▲	=	=	▼	▲
rise rate	▲	=			
fall rate	△				▲
number of reversals	▲	△	▽		▽
Frequency					
high pulse count	▲	=	▽		▽
ext. low flow frequency	▲	=		▽	▲
Duration					
high flow index MH21	▼	▼		△	▼
high pulse duration	▼	=			
high flow duration DH17	▼	▽			▼
low pulse duration	▼		△	▼	△



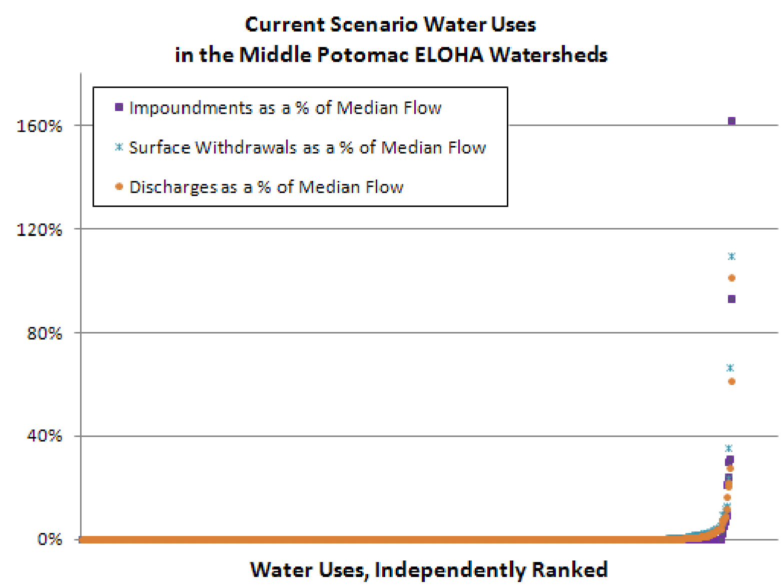


Figure 1. Distribution of current model scenario land and water uses amongst the 747 ELOHA watersheds.

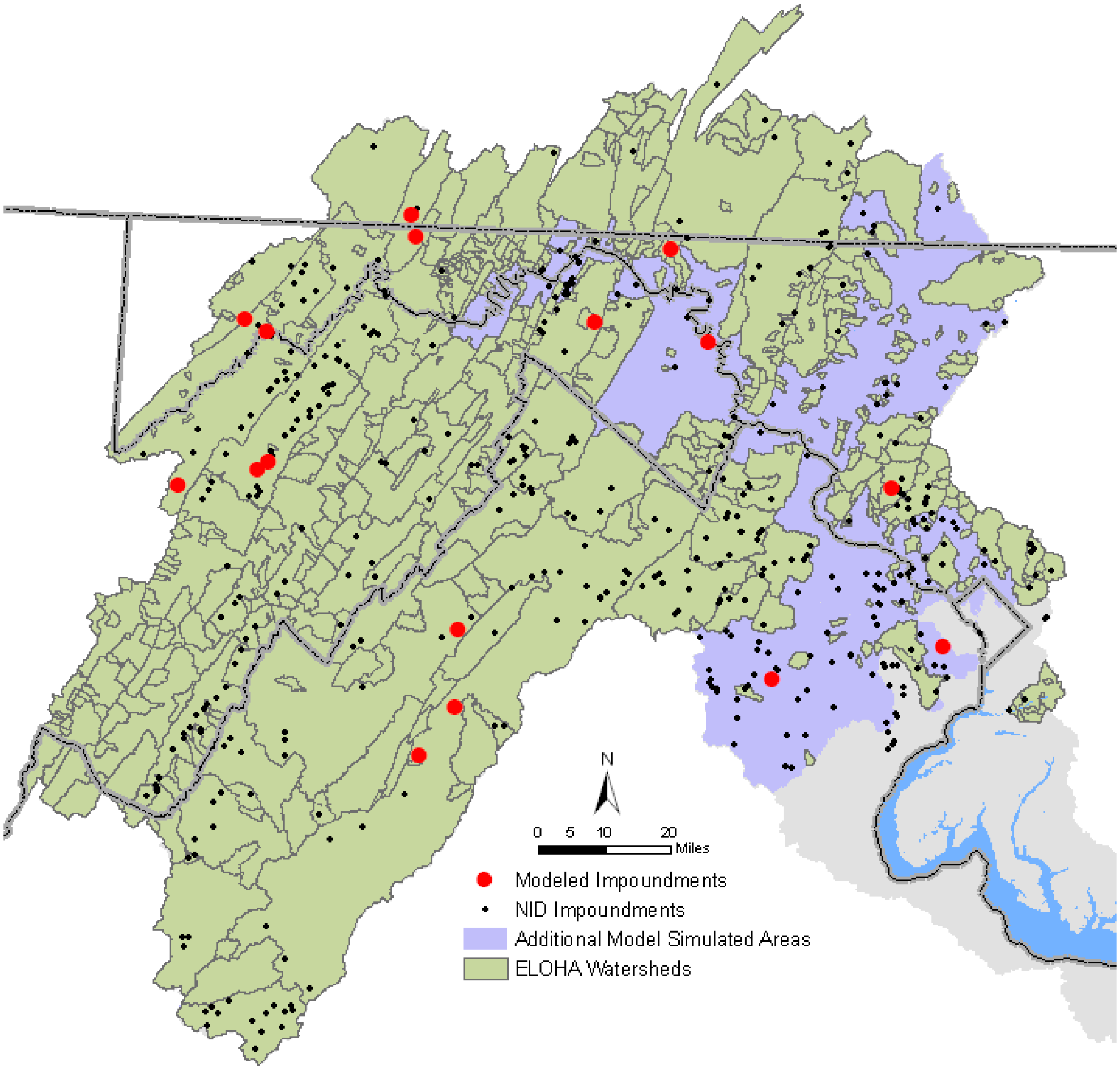


Figure 2. Location of modeled impoundments and all NID impoundments in the model simulated area.

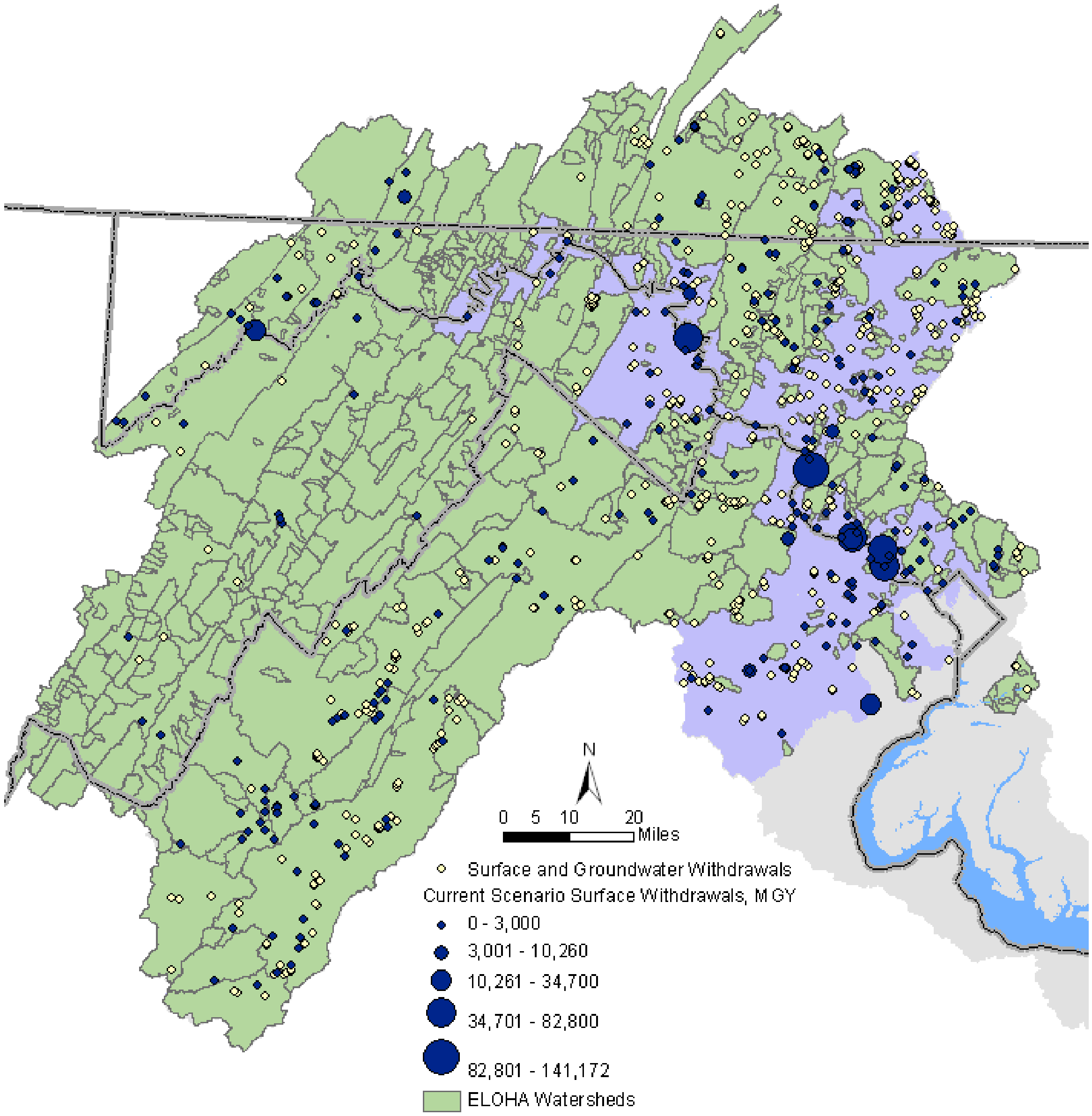


Figure 3. Withdrawal locations in the model simulated area.

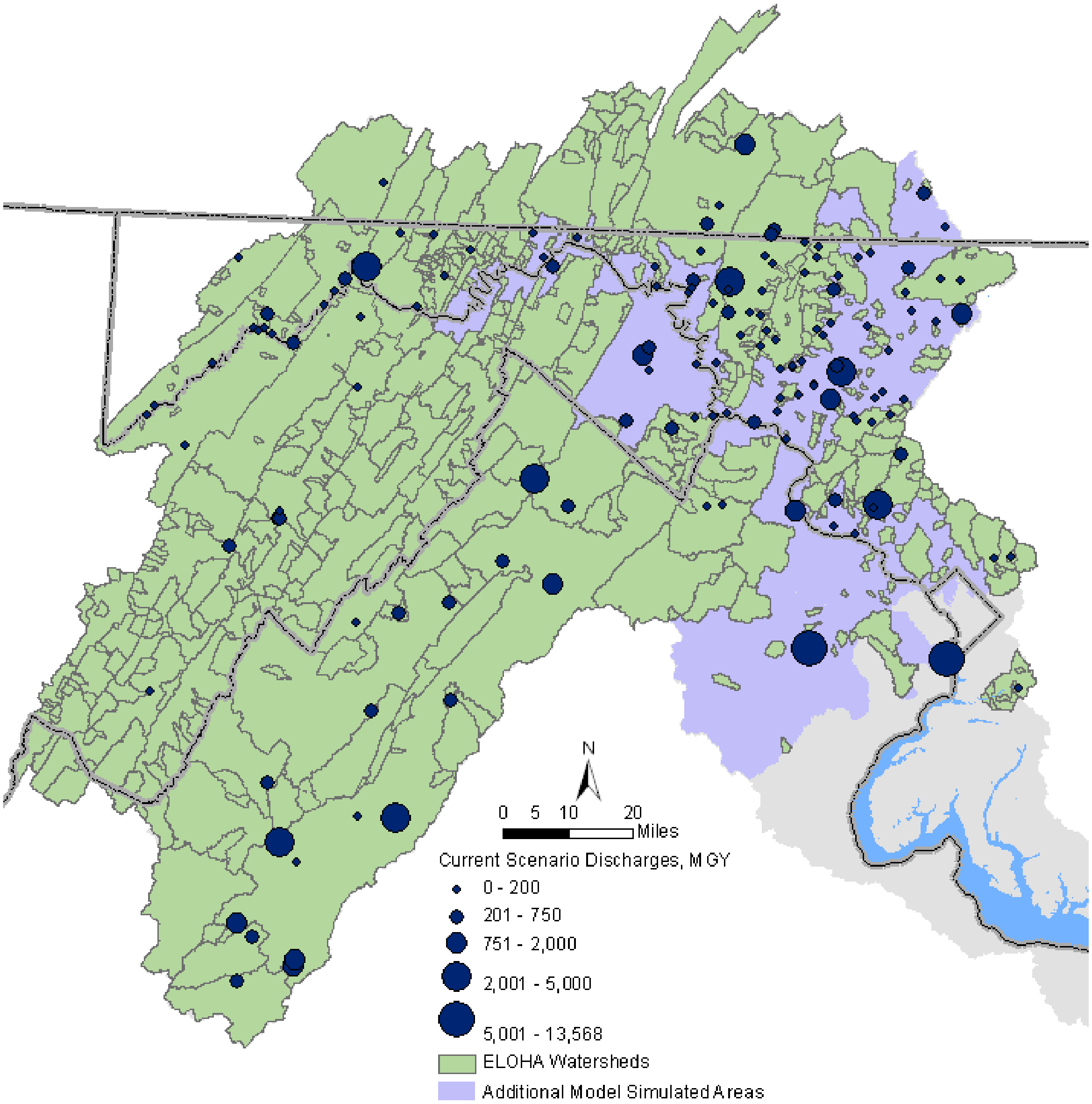


Figure 4. Location of current scenario discharges.

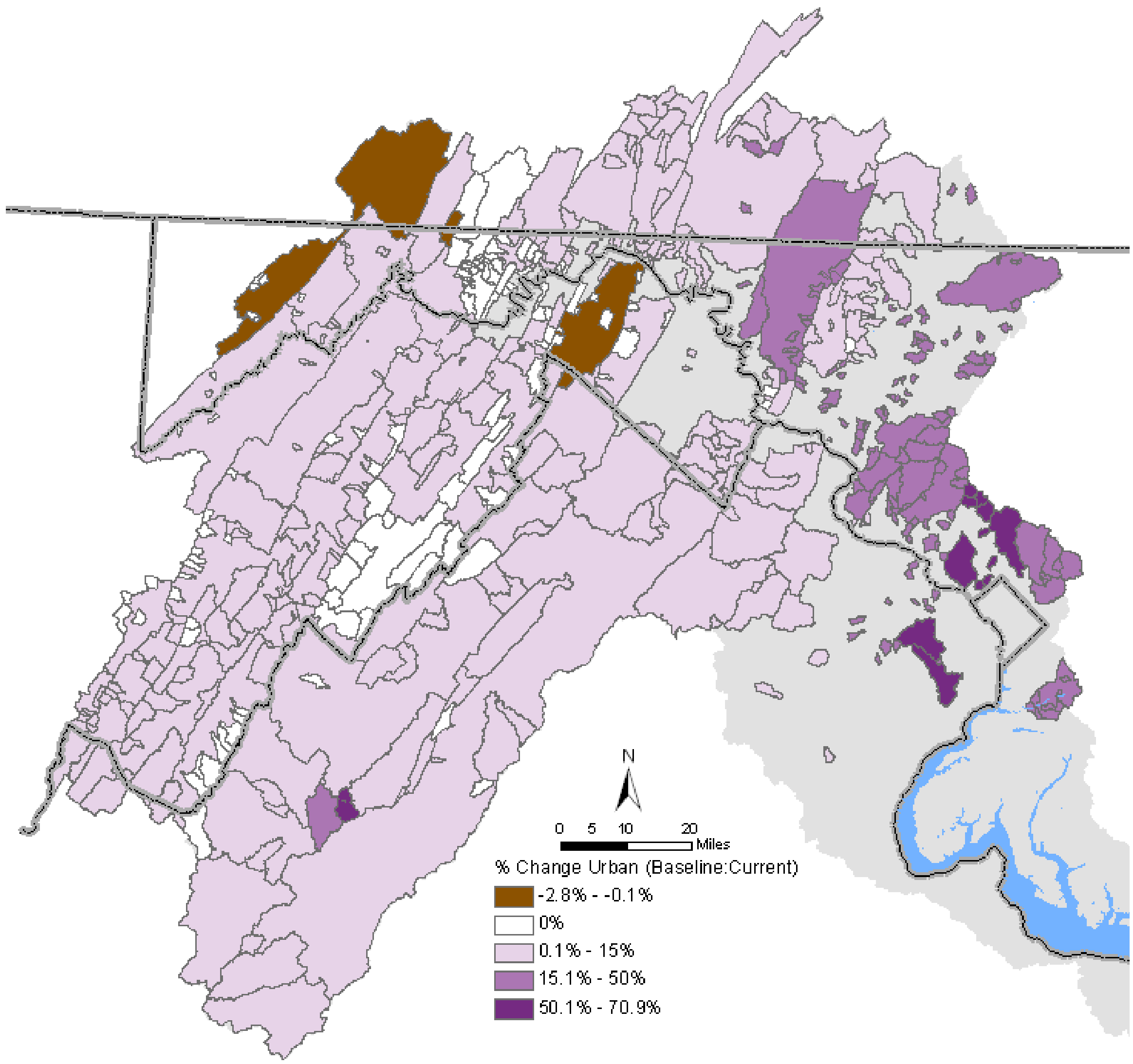


Figure 5. Percent change in urban areas between the baseline and current scenarios. A positive value indicates that urban areas increased between baseline and current conditions.

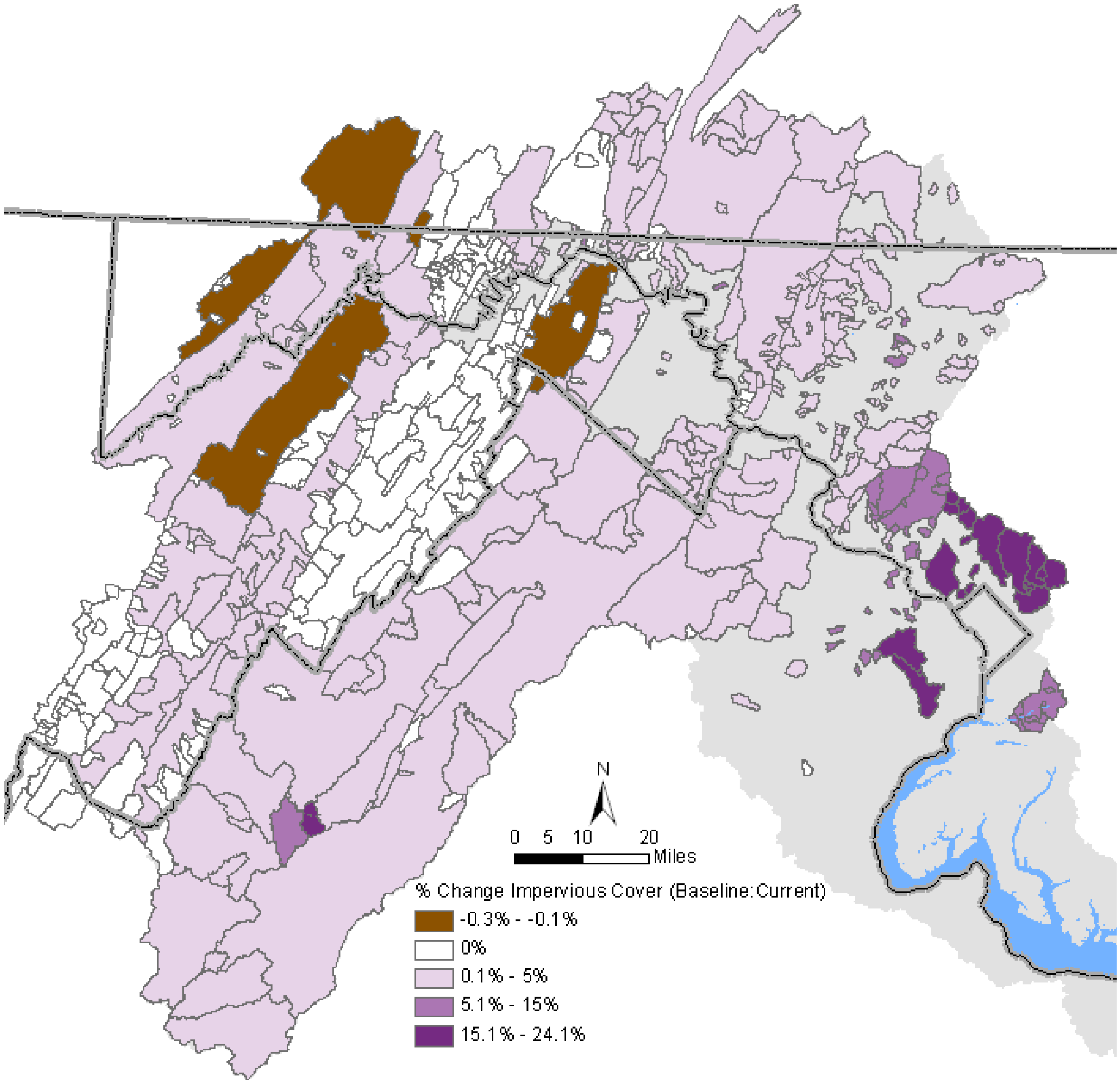


Figure 6. Percent change in impervious cover between the baseline and current scenarios. A positive value indicates that impervious cover increased between baseline and current conditions.

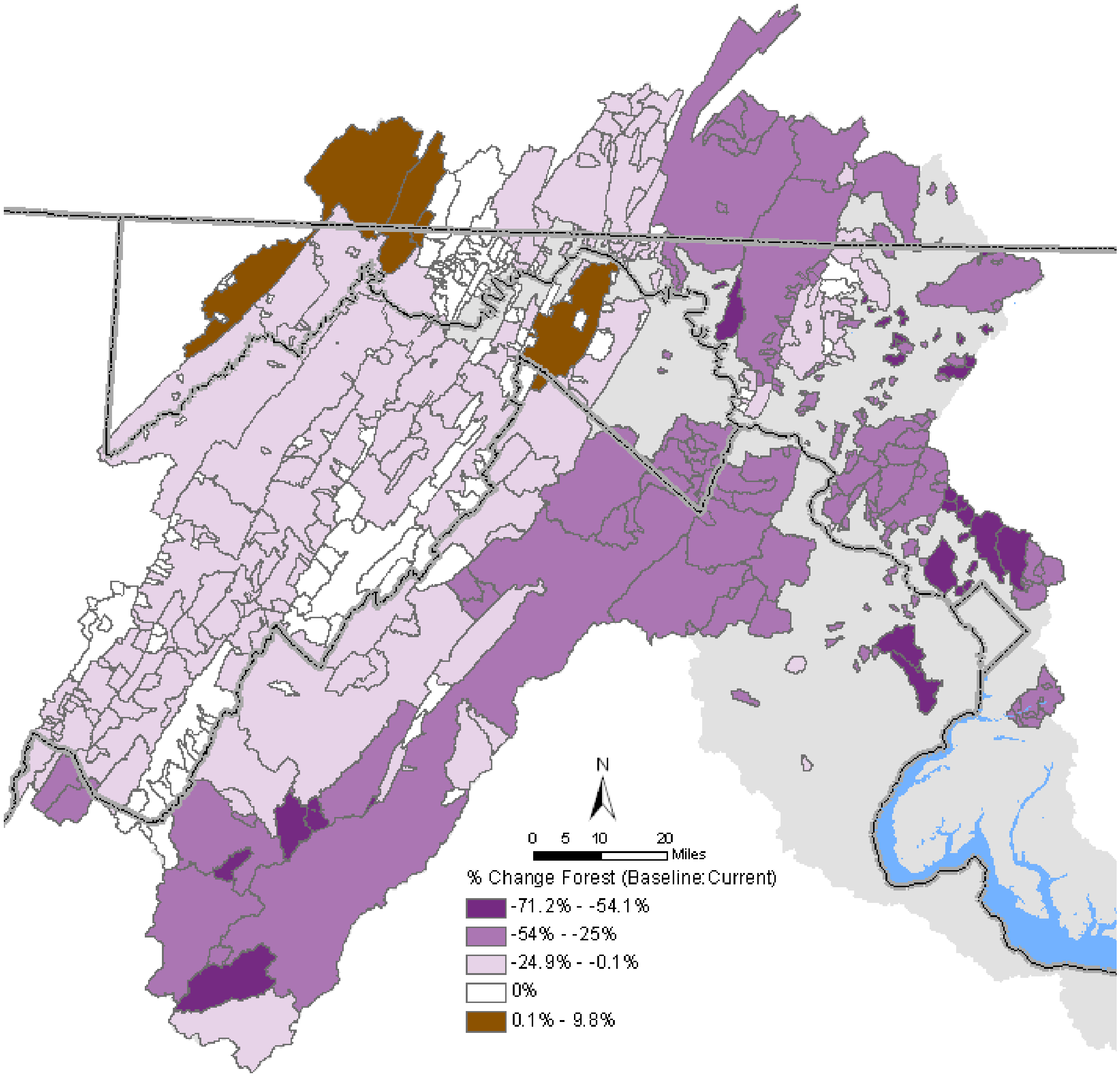


Figure 7. Percent change in forest between the baseline and current scenarios. A positive value indicates that the amount of forest increased between baseline and current conditions.

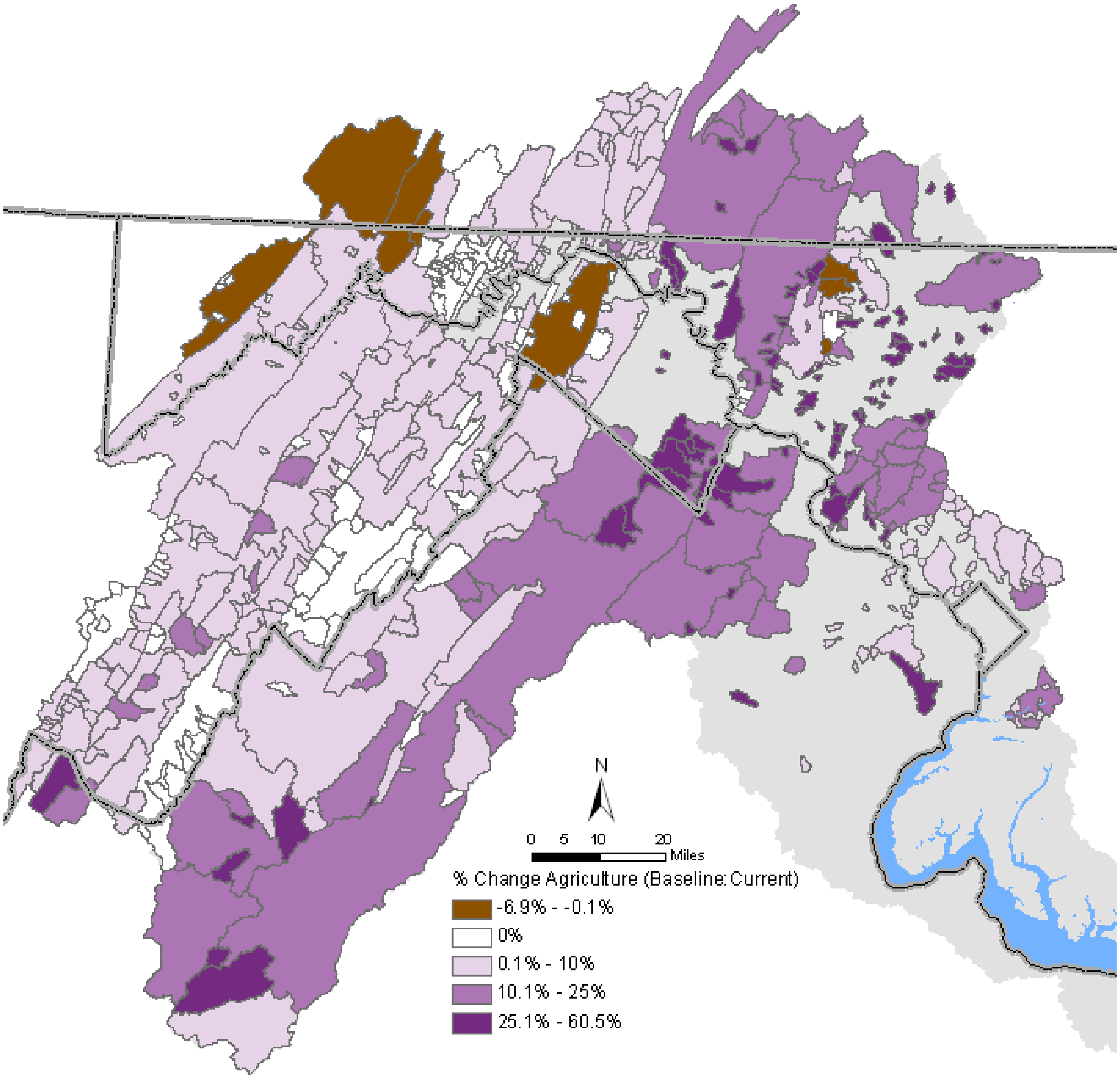


Figure 8. Percent change in agriculture between the baseline and current scenarios. A positive value indicates that the amount of agriculture increased between baseline and current conditions.

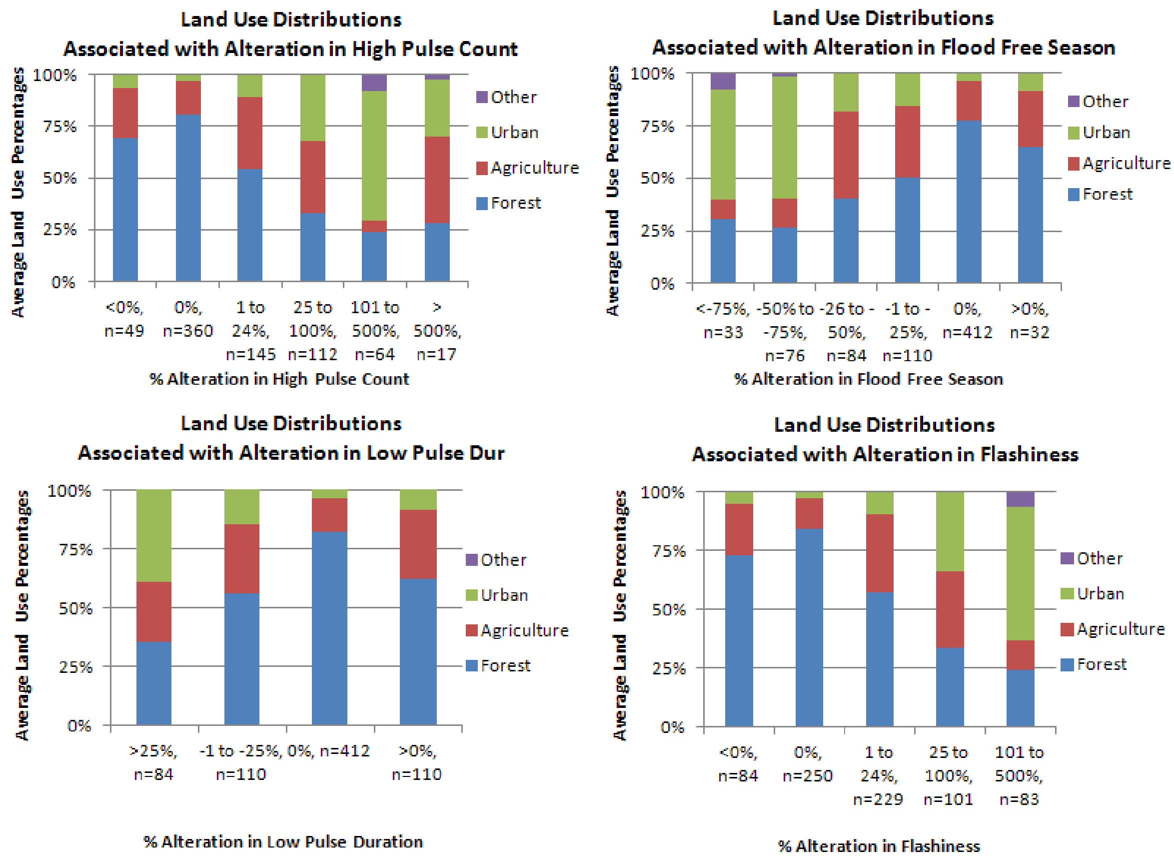


Figure 9. Linkages between flow alteration and land use characteristics.

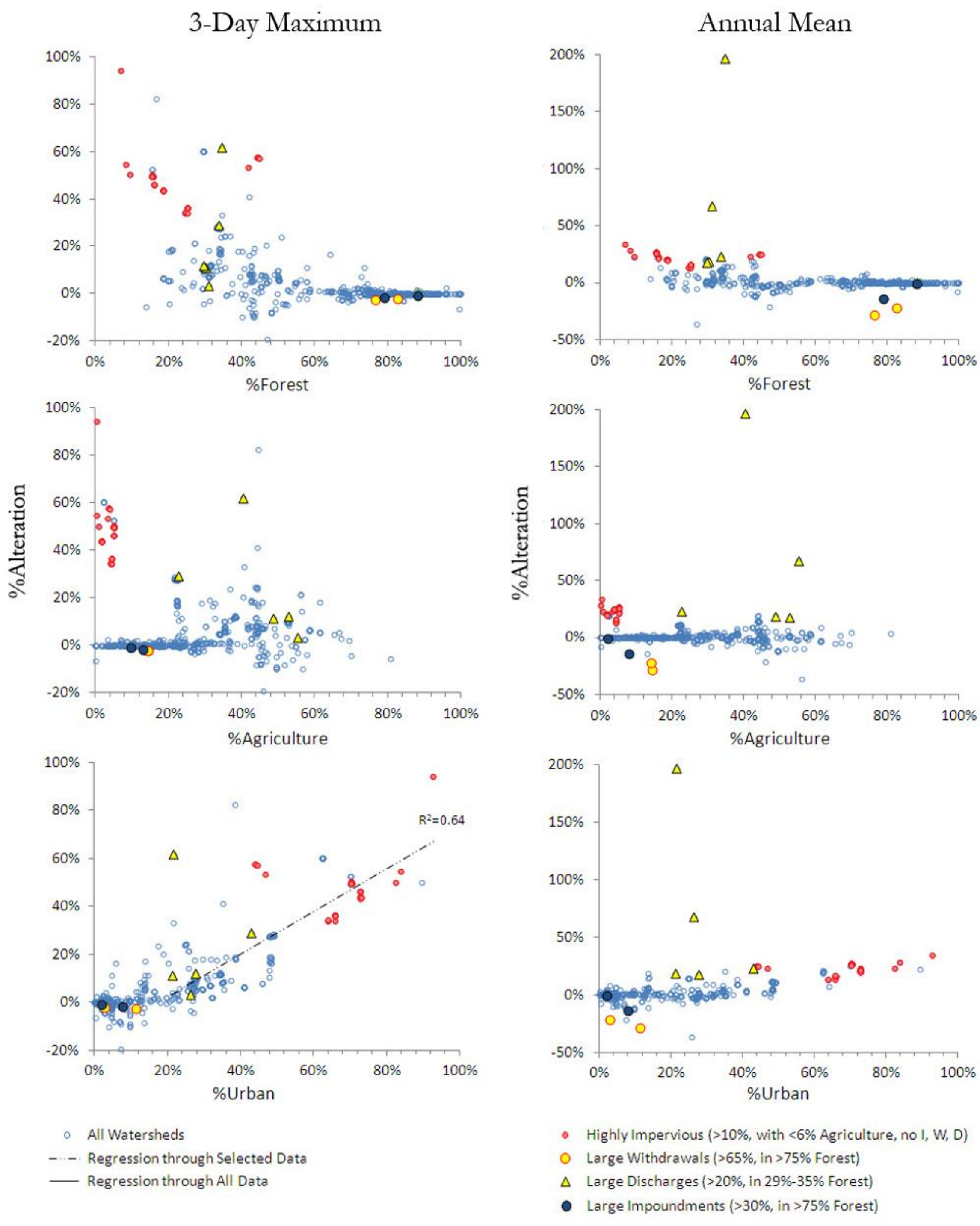


Figure 10. Flow alteration in 3-day maximum and annual mean flow versus percent forest, percent agriculture, and percent urban. See text for details.

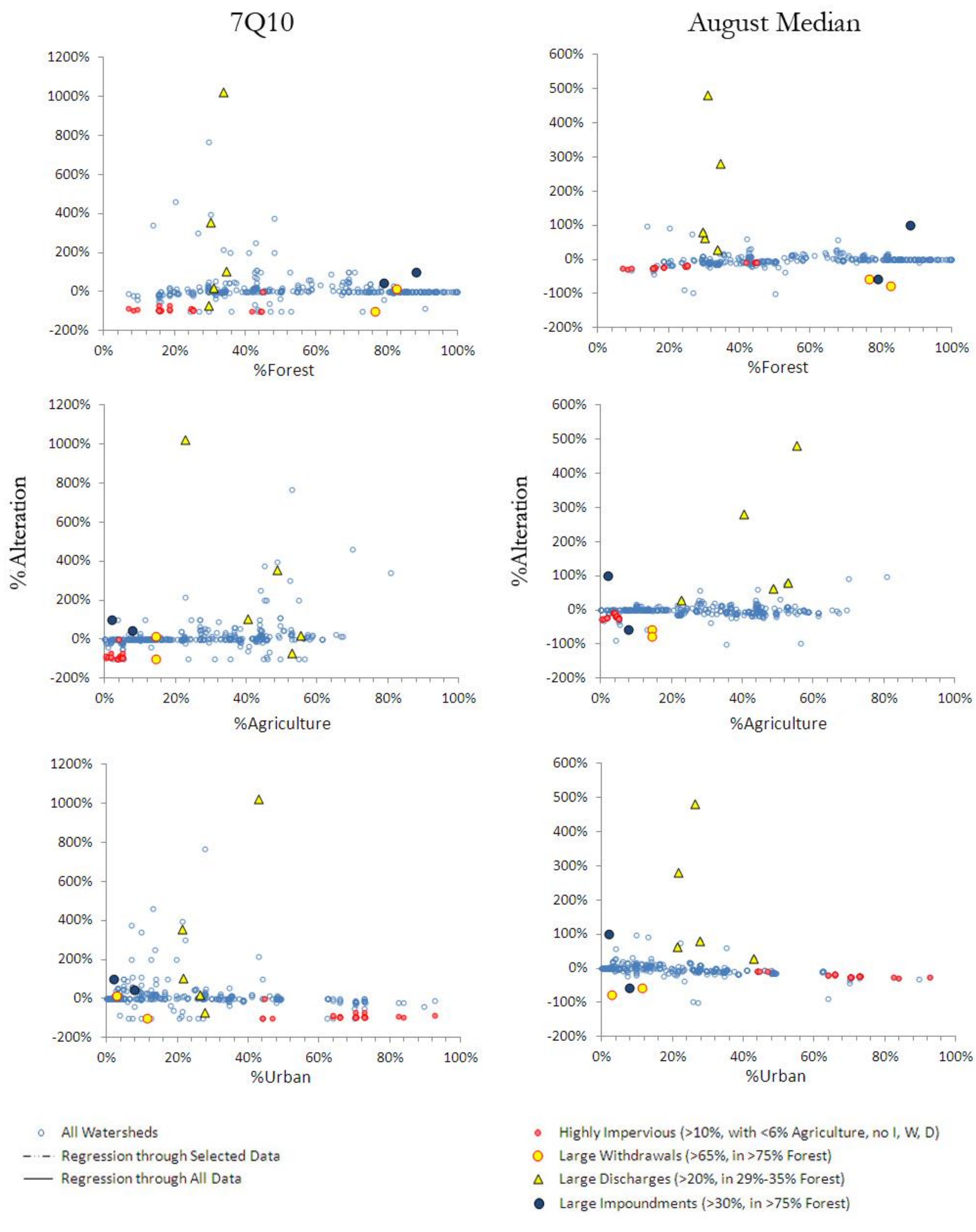


Figure 10 (cont.). Flow alteration in 7Q10 and August median versus percent forest, percent agriculture, and percent urban. See text for details.

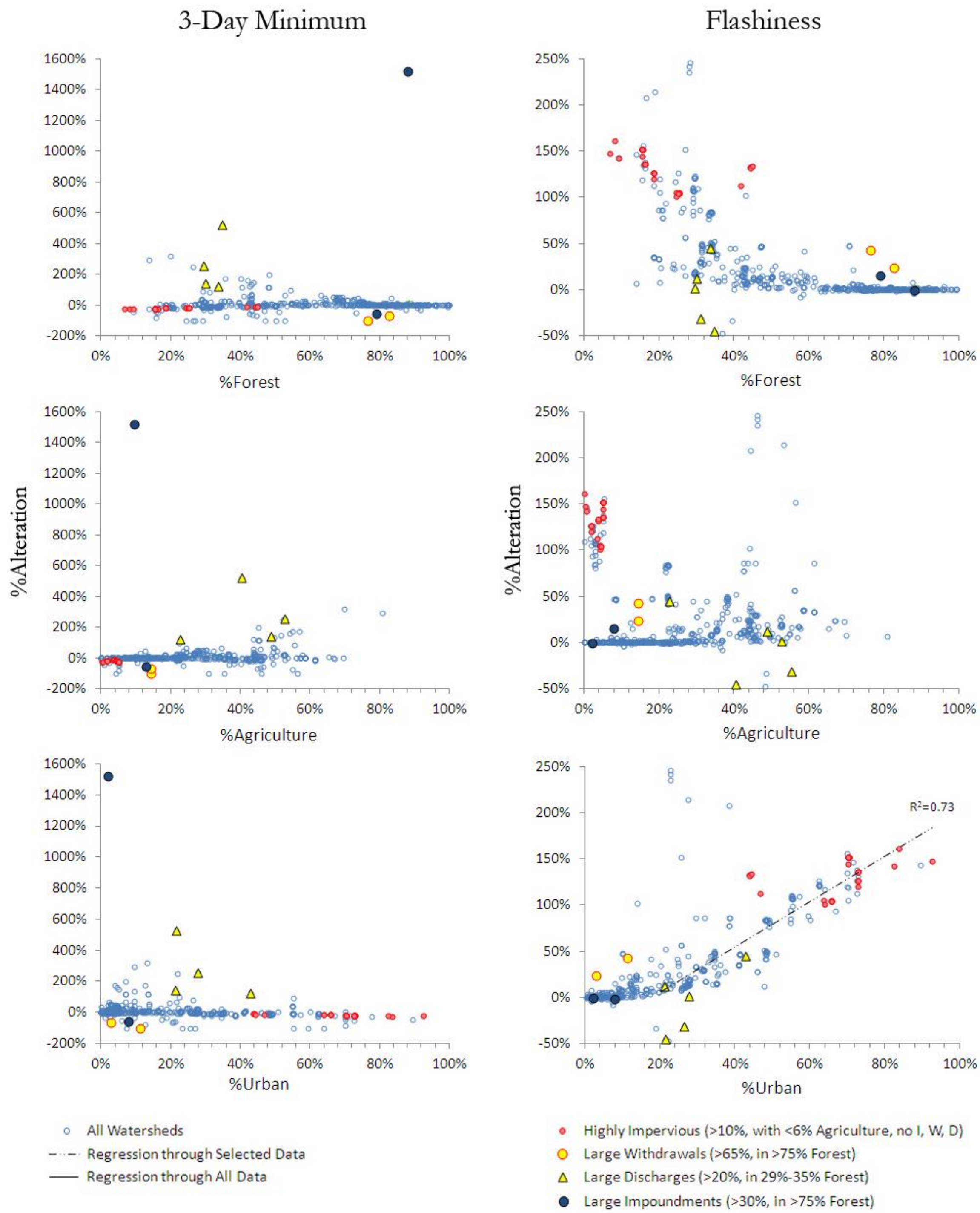


Figure 10 (cont.). Flow alteration in 3-day minimum and flashiness versus percent forest, percent agriculture, and percent urban. See text for details.

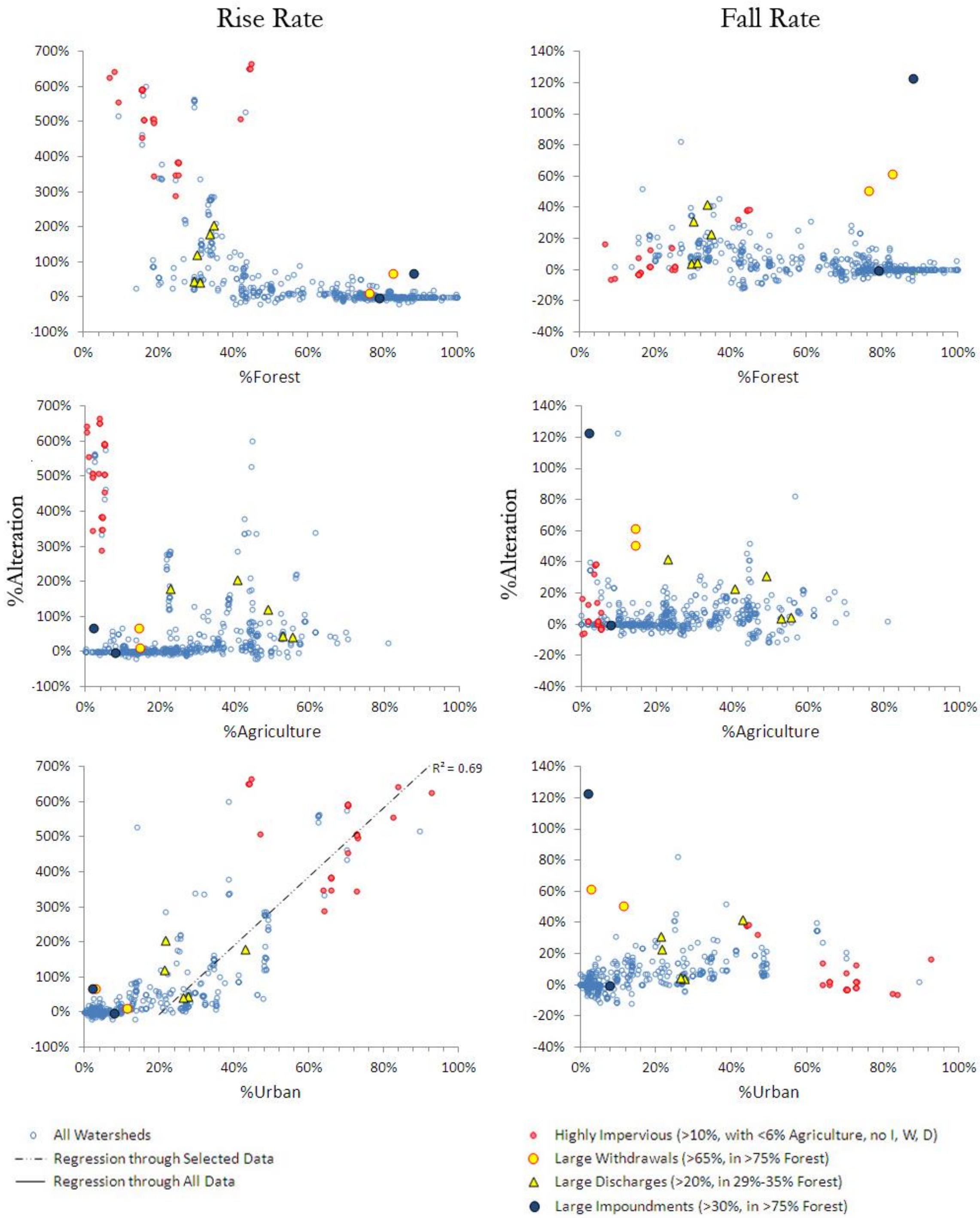


Figure 10 (cont.). Flow alteration in rise rate and fall rate versus percent forest, percent agriculture, and percent urban. See text for details.

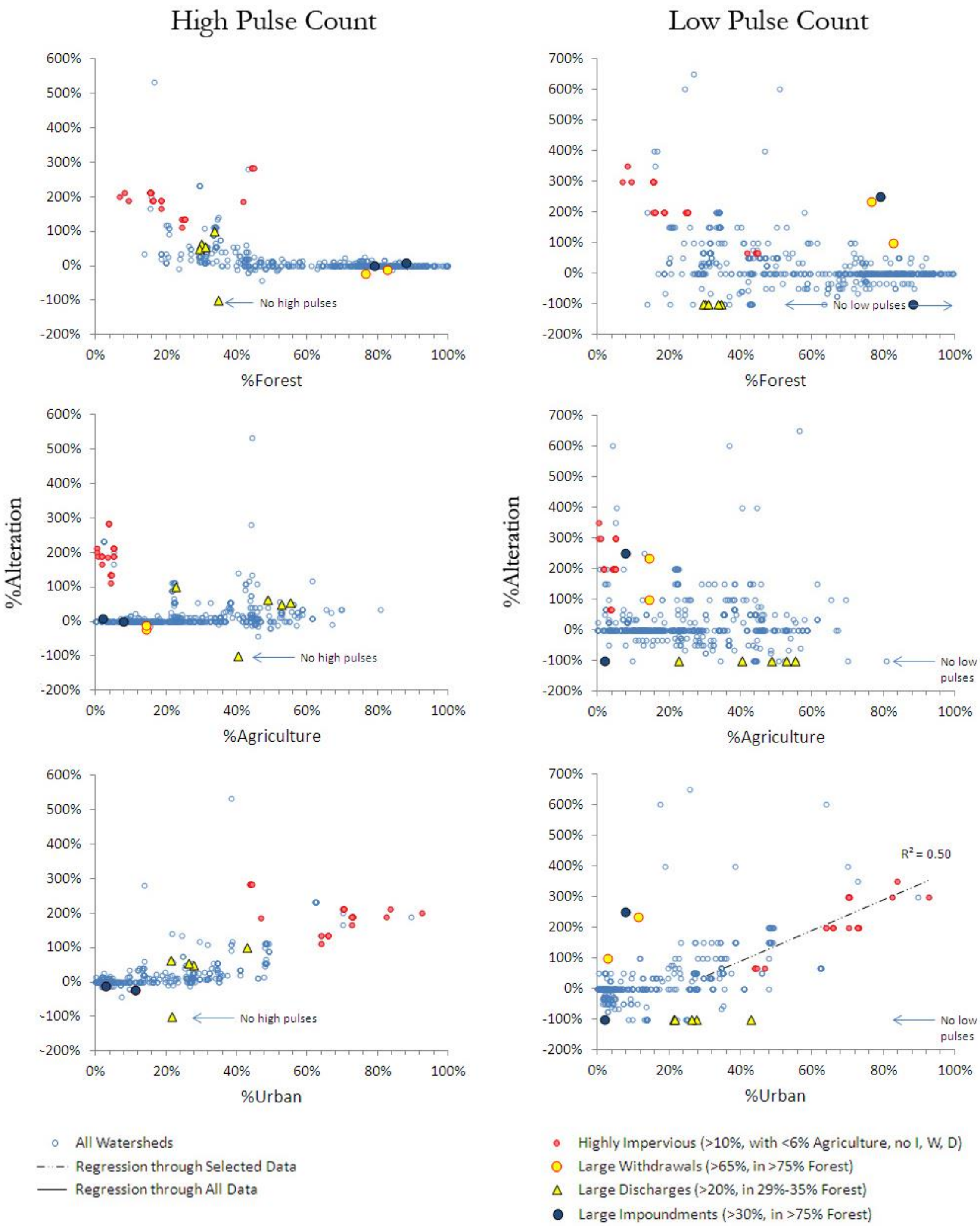


Figure 10 (cont.). Flow alteration in high pulse count and low pulse count versus percent forest, percent agriculture, and percent urban. See text for details.

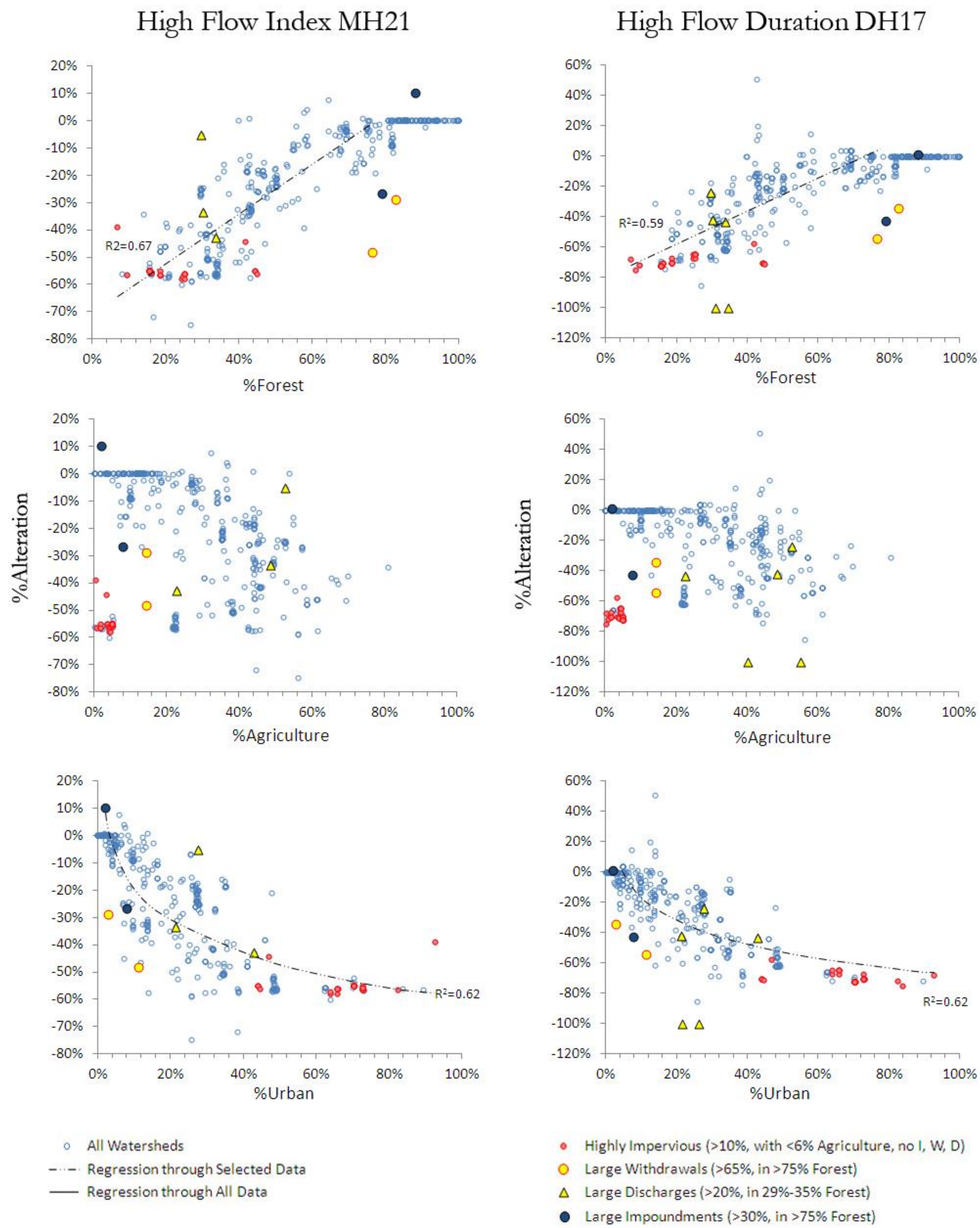


Figure 10 (cont.). Flow alteration in high flow index MH21 and high flow duration DH17 versus percent forest, percent agriculture, and percent urban. See text for details.

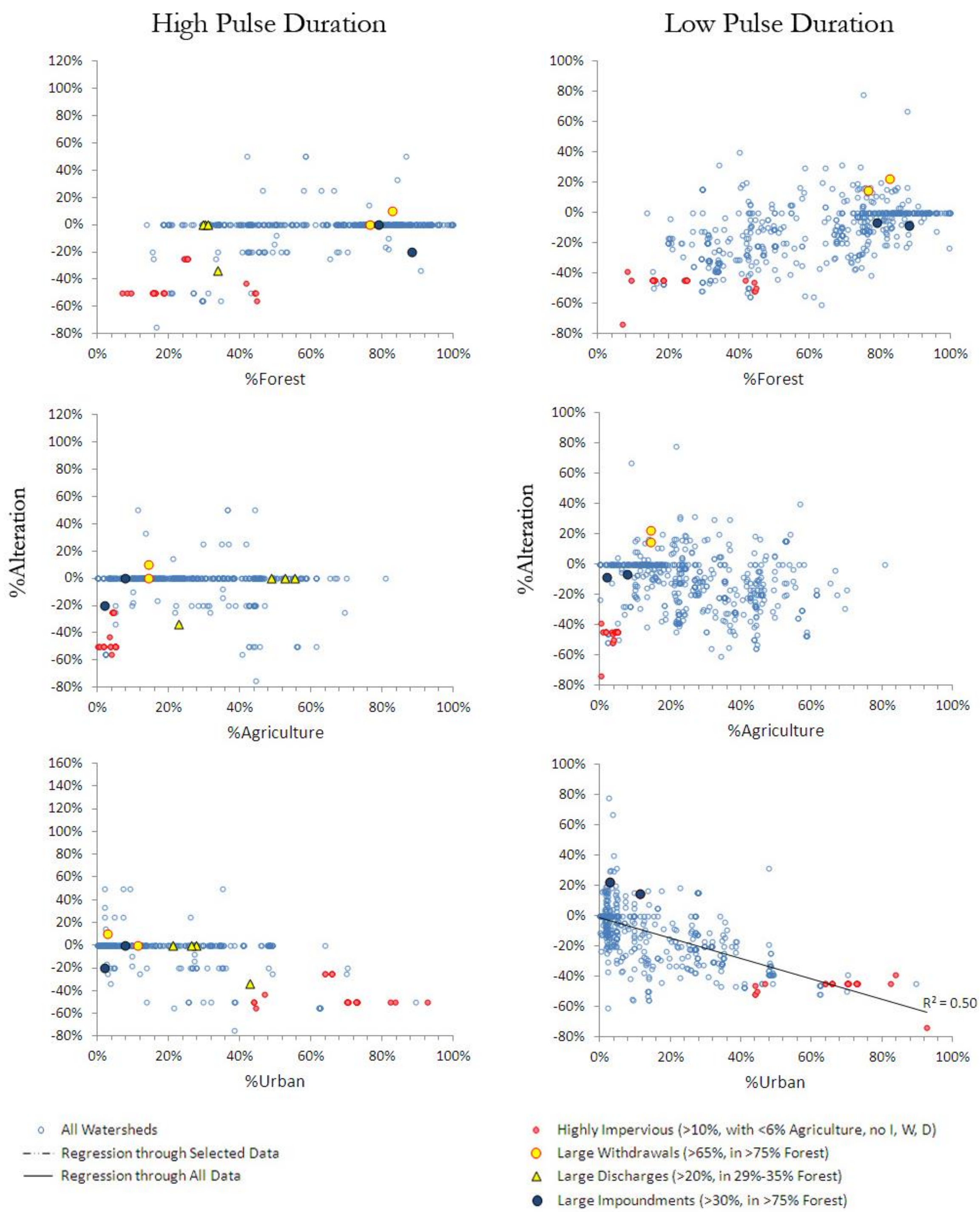


Figure 10 (cont.). Flow alteration in high pulse duration and low pulse duration versus percent forest, percent agriculture, and percent urban. See text for details.

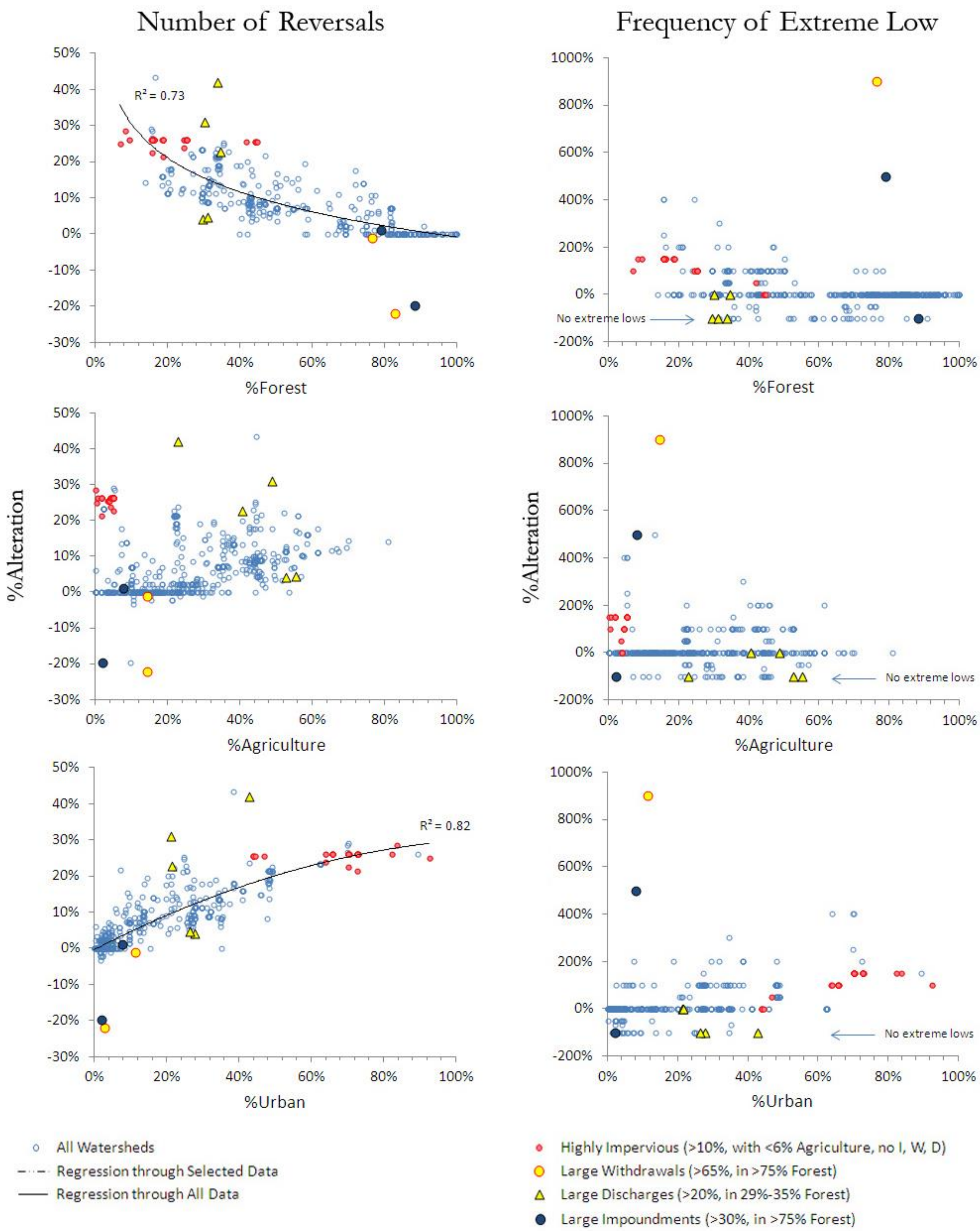


Figure 10 (cont.). Flow alteration in number of reversals and extreme low flow frequency versus percent forest, percent agriculture, and percent urban. See text for details.

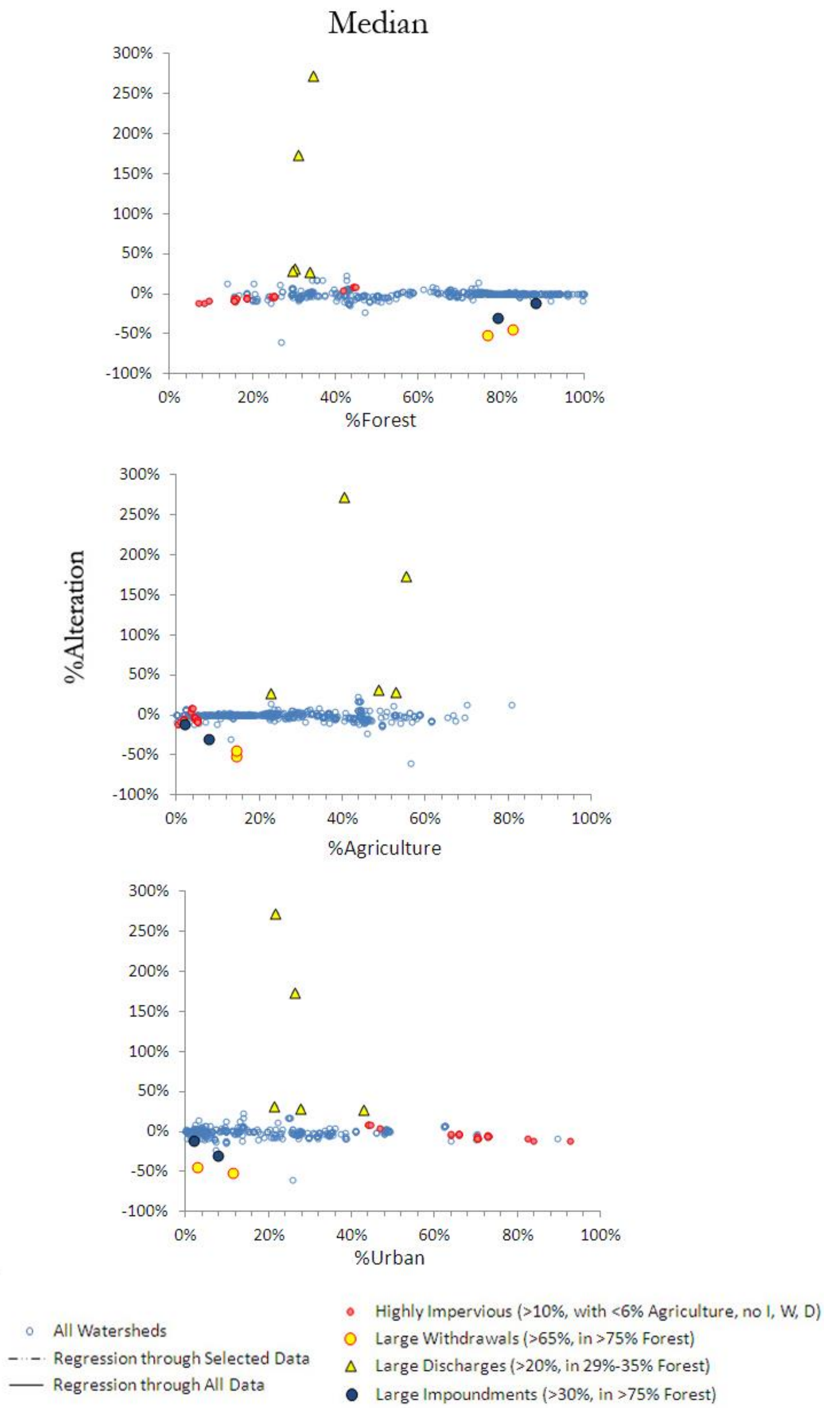


Figure 10 (cont.). Flow alteration in median flow versus percent forest, percent agriculture, and percent urban. See text for details.

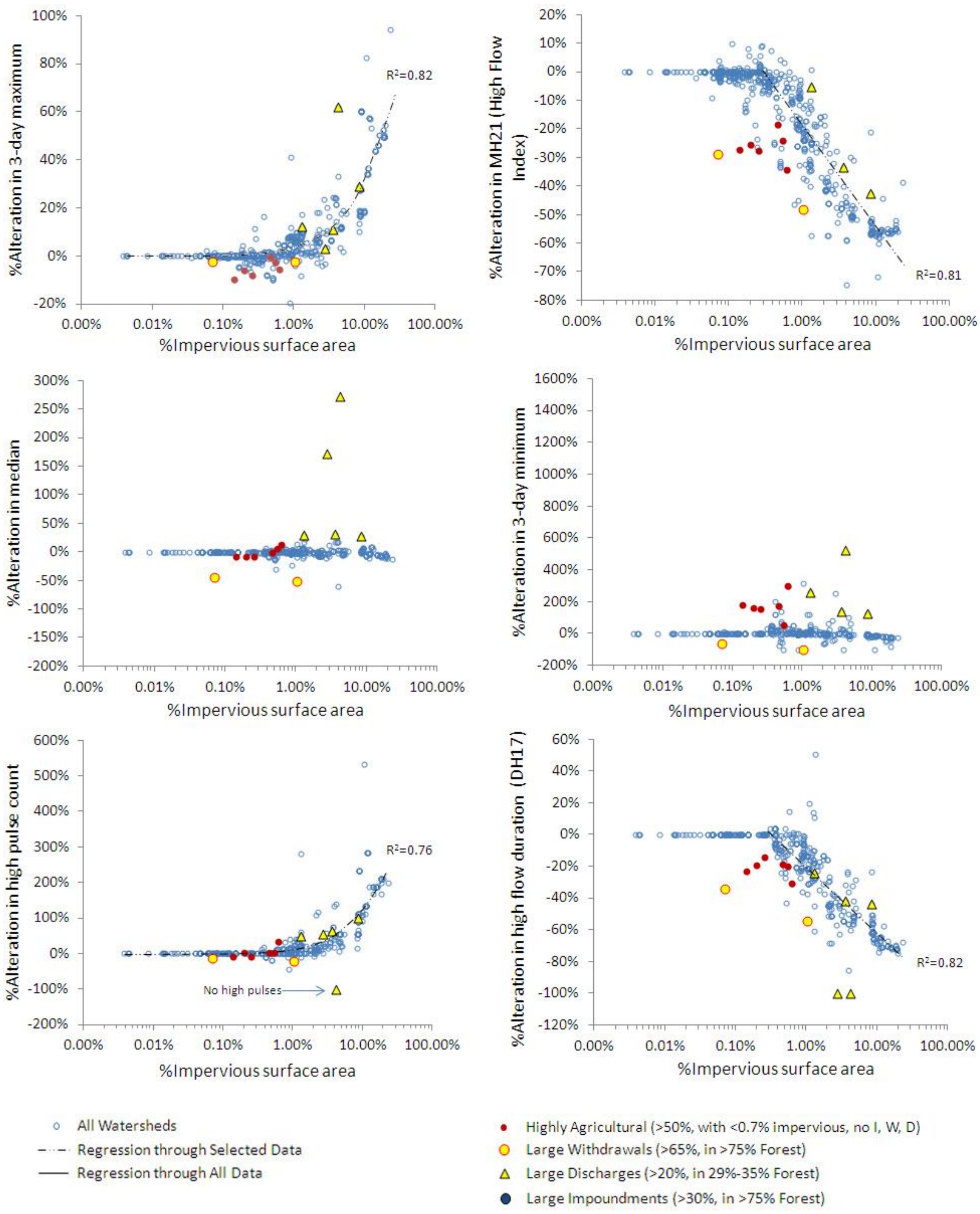


Figure 11. Relationship of percent impervious surface with 3-day maximum, annual mean, median, 3-day minimum, high pulse count, and high flow duration DH17. See text for details.

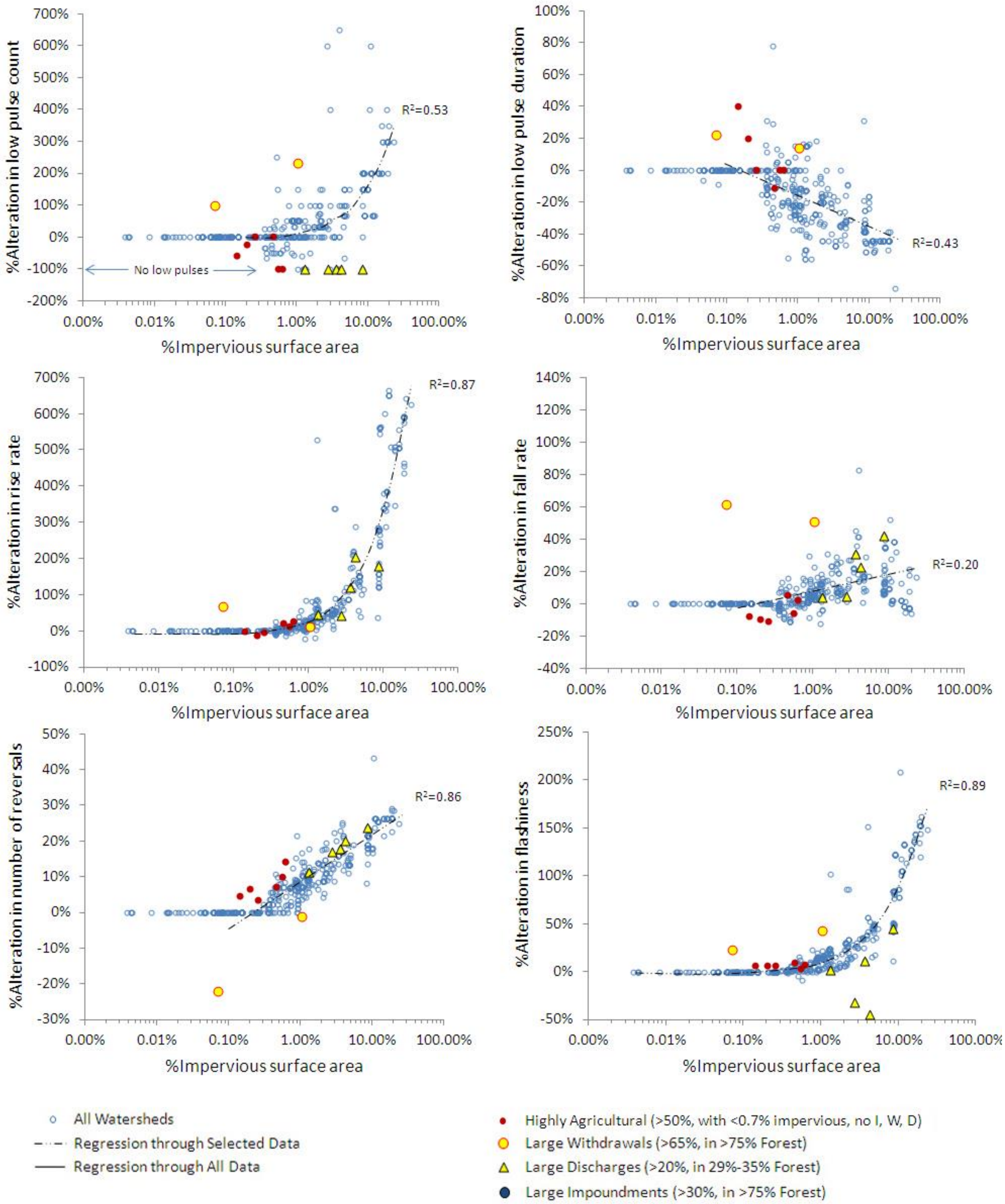


Figure 11 (cont.). Relationship of percent impervious surface with low pulse count, low pulse duration, rise rate, fall rate, number of reversals, and flashiness. See text for details.