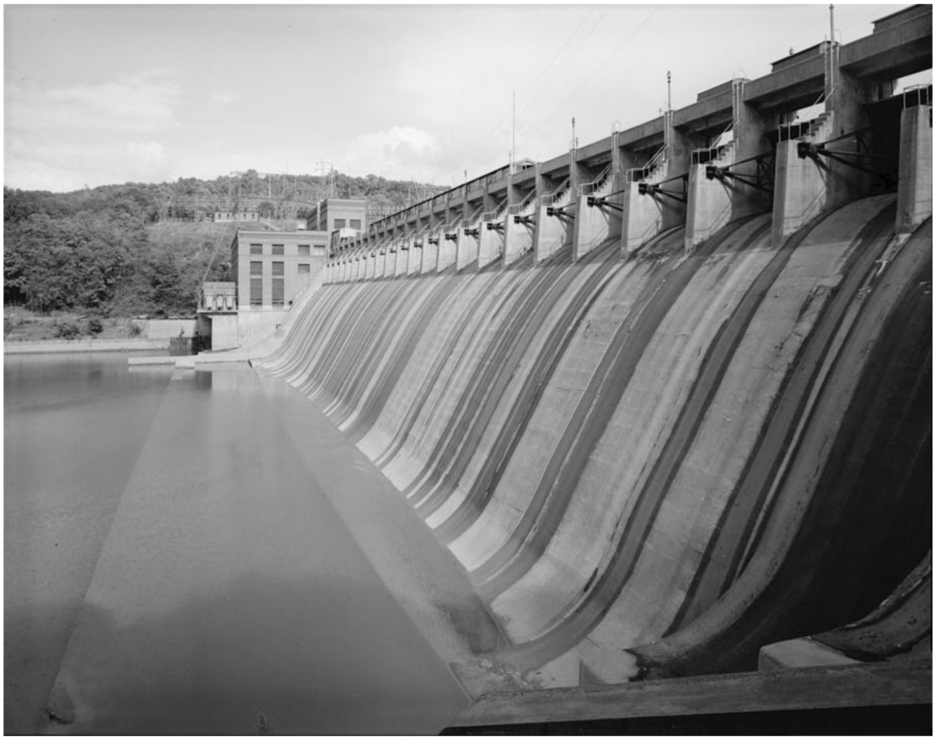
Impact of Anthropogenic Activities on Low Flows in West Virginia



Prepared for
West Virginia Department of Environmental Protection

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Table of Contents

List of Tables

List of Figures

Abbreviations

7Q10	Lowest 7-day average flow likely to occur once every 10 years
DEP	West Virginia Department of Environmental Protection
EPA	United States Environmental Protection Agency
GIS	Geographic Information Systems
HUC8	8-Digit Hydrologic Unit Code
ICPRB	Interstate Commission on the Potomac River Basin
MPRWA	Middle Potomac River Watershed Assessment
TAGIS	DEP Technical Applications and GIS Unit
U.S.	United States
USGS	United States Geological Survey
WV	West Virginia

Units of Measurement

Mgal/y	Million gallons per year
sqmi	Square miles

1 Introduction

The Water Resources Protection and Management Act of 2008[1] required West Virginia Department of Environmental Protection (DEP) to identify potential in-stream or off-stream uses that could affect natural streamflow, especially low-flow conditions, to the detriment of water resources. Many human activities utilize water resources, from domestic use to the production of materials and energy needed by modern society. A number of anthropogenic activities have the potential to negatively impact low-flow conditions in streams, including land uses, dams, mountaintop mining, and water withdrawals and discharges. This study evaluates these anthropogenic activities across West Virginia and considers to what extent they may impact low flows. The Middle Potomac River Watershed Assessment (MPRWA) (U.S. Army Corps of Engineers et al. 2012) provides the primary source of information on the quantitative relationships between humans and low flows.

2 Anthropogenic Factors

2.1 Land Use Changes

Human populations and their use of the land have direct impacts on the hydrologic cycle[2]. For example, increasing impervious cover in urban areas causes the streams to become more "flashy." In these urban systems, precipitation does not have the opportunity to infiltrate the soil due to roads, rooftops, parking lots, and other impervious surfaces. Instead, the water quickly runs off over the land surface to nearby waterways. As a result, less precipitation is able to recharge the groundwater aquifer, the source of streamflow during low-flow periods. To this end, the current and future West Virginia land use characteristics may influence low-flow conditions in the state.

Utilizing readily available data sets[3], it was determined that the total decrease in forested area (represented by a change in forested land to any other land cover type) for all watersheds was 132 square miles (sqmi), a 0.7 percent decrease (**Table 1** and **Figure 1**). The total increase in developed land was 35 sqmi, a 2 percent increase (**Table 1** and **Figure 2**). There was a decrease in agricultural land of 11 sqmi, a 0.5 percent decrease (**Table 1** and **Figure 3**). The change in impervious area for each watershed was calculated as a percent of the total area of the watershed (**Table 1** and **Figure 4**). The total increase in impervious area was 18 sqmi, or 0.07 percent of the area of the state (**Table 1**).

[1] West Virginia Code Chapter 22. Environmental Resources. Article 26. Water Resources Protection Act. http://www.legis.state.wv.us/WVCODE/ChapterEntire.cfm?chap=22&art=26, accessed 2/22/2013.
[2] See the projection of future consumptive uses for a discussion of possible future West Virginia population changes.
[3] The USGS National Land Cover Database (NLCD) 2006 From – To Change Index (Fry et al. 2011) and the USGS NLCD 2001/2006 Percent Developed Imperviousness Change.

Table 1. Percent change in forest, developed, agriculture, and impervious cover by 8-digit Hydrologic Unit Code (HUC8) watershed. The final row of the table is the percent change for all watersheds.

HUC8	Percent Change in Forest Land	Percent Change in Developed Land	Percent Change in Agriculture Land	Percent Change in Impervious Cover
South Branch Potomac	-0.2	1.9	-0.1	0.0
North Branch Potomac	-0.7	0.3	0.1	0.0
Cacapon	-0.5	2.1	-0.1	0.0
Potomac Direct Drains	-1.6	15.1	-1.5	0.7
Shenandoah Hardy	-0.2	0.0	0.0	0.0
Shenandoah Jefferson	-2.2	12.4	-1.8	1.0
James	-9.0	0.0	-0.1	0.0
Tygart Valley	-0.4	0.4	0.5	0.0
West Fork	-0.1	1.3	-0.7	0.1
Monongahela	-1.2	5.5	0.0	0.3
Cheat	-0.3	1.0	0.5	0.0
Dunkard	-0.6	0.0	0.3	0.0
Youghiogheny	-1.1	0.0	2.5	0.0
Upper Ohio North	-2.6	6.4	0.1	0.7
Upper Ohio South	-1.0	6.1	-0.5	0.3
Middle Ohio South	0.0	0.0	0.0	0.0
Upper Ohio-Shade	-0.1	1.5	0.0	0.1
Little Kanawha	0.0	0.8	-0.1	0.0
Upper New	-0.2	2.3	-0.7	0.1
Greenbrier	-0.6	0.5	-0.6	0.0
Lower New	-0.1	4.1	-2.0	0.2
Gauley	-2.7	0.9	-0.7	0.0
Upper Kanawha	-0.8	0.8	-6.0	0.0
Elk	-0.2	0.3	0.1	0.0
Lower Kanawha	-0.2	1.7	-0.1	0.1
Coal	-2.0	0.9	-2.5	0.0
Upper Guyandotte	-1.8	0.3	-5.1	0.0
Lower Guyandotte	-0.6	1.9	-1.3	0.1
Tug Fork	-1.1	-0.1	-6.0	0.0
Big Sandy	0.2	0.4	-1.2	0.0
Lower Ohio	-0.1	0.8	-0.3	0.1
Twelvepole	0.0	0.6	-2.5	0.0
All watersheds	-0.7%	2.1%	-0.5%	0.1%

The MPRWA illustrates how the state's land use changes may impact low flows. A major finding of the MPRWA was the strong relationships between impervious surface, flow alteration, and significant ecological impacts (U.S. Army Corps of Engineers et al. 2012). Streamflow flashiness and the number and magnitude of high flow events start to increase when total impervious surface area in a watershed exceeds 0.5 - 2.0 percent (U.S. Army Corps of Engineers et al. 2012). Impervious cover also has the potential to reduce groundwater recharge by reducing infiltration area and thus reduce baseflows, especially during low-flow conditions.

Figure 1. Change in forest NLCD land cover 2001 – 2006 by HUC8 watershed.

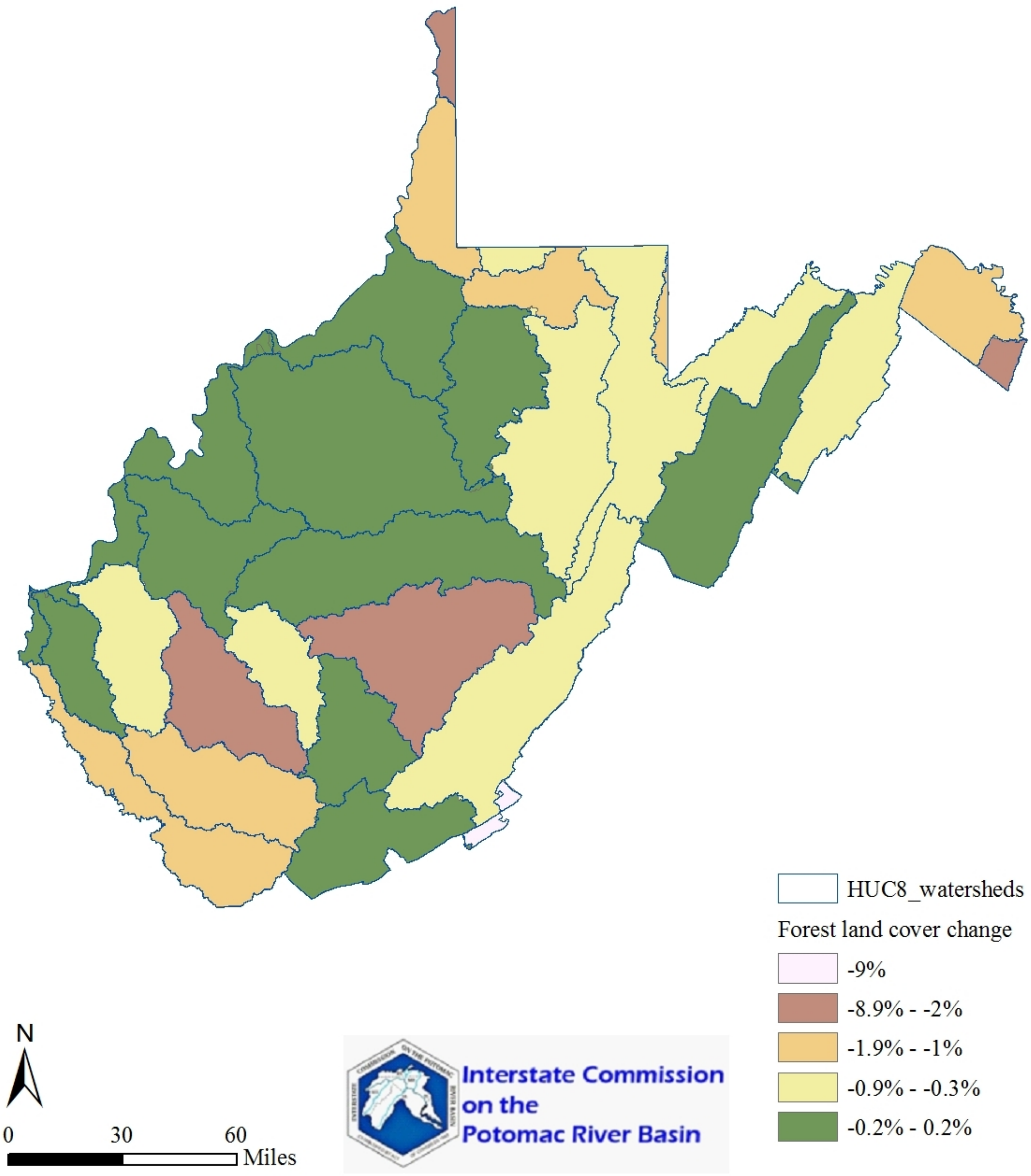


Figure 2. Change in developed NLCD land cover 2001 – 2006 by HUC8 watershed.

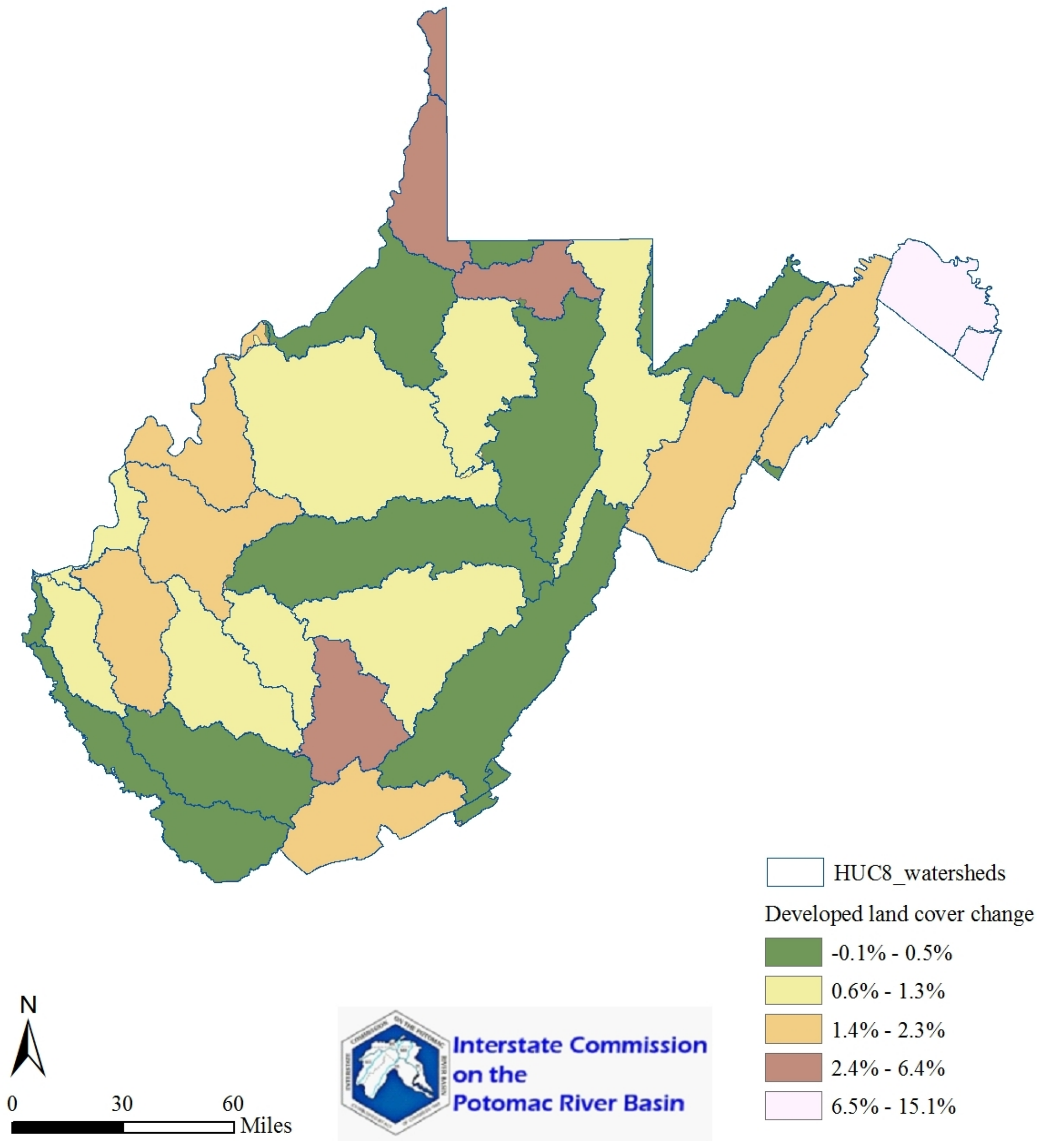


Figure 3. Change in agricultural NLCD land cover 2001 – 2006 by HUC8 watershed.

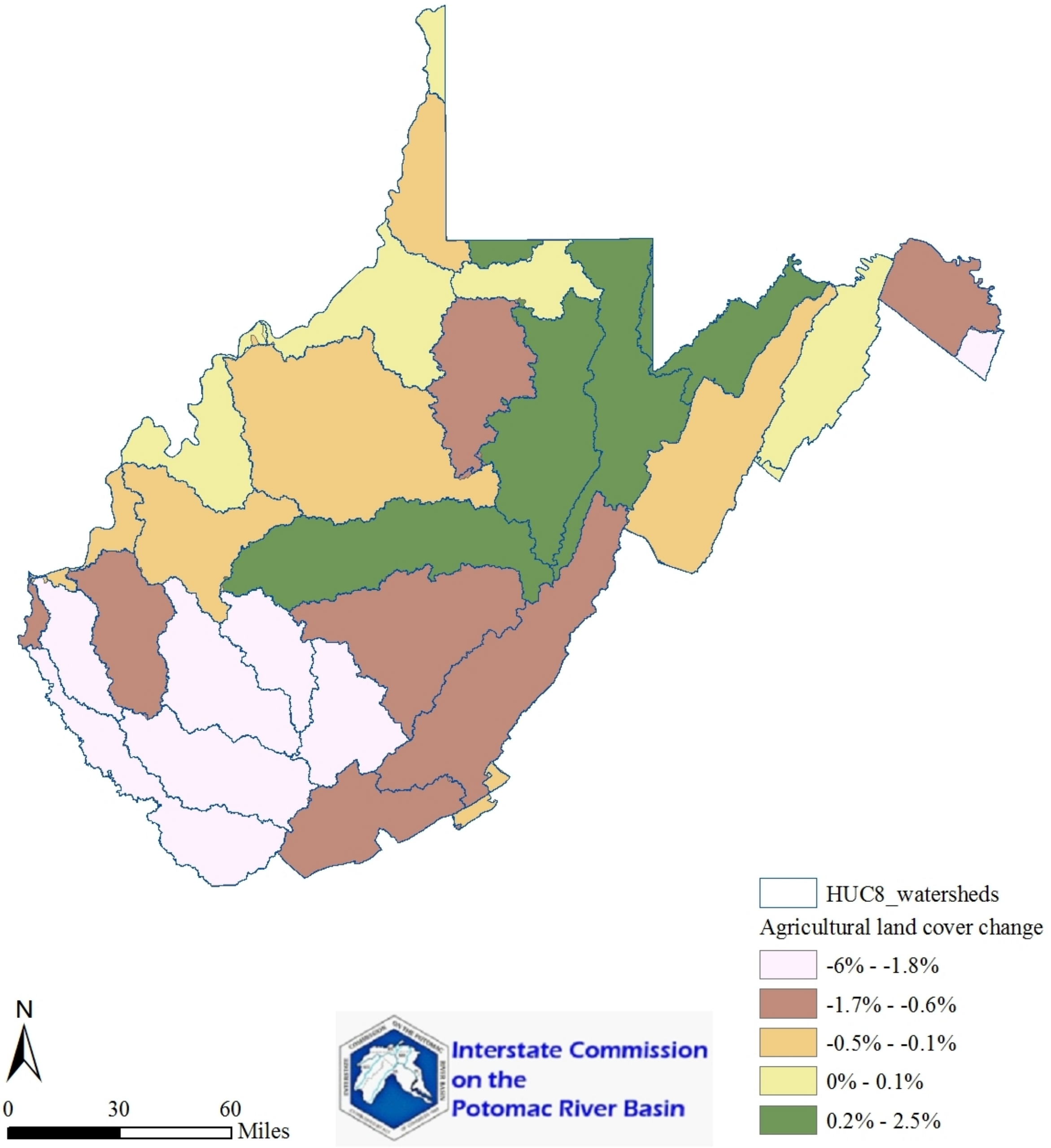
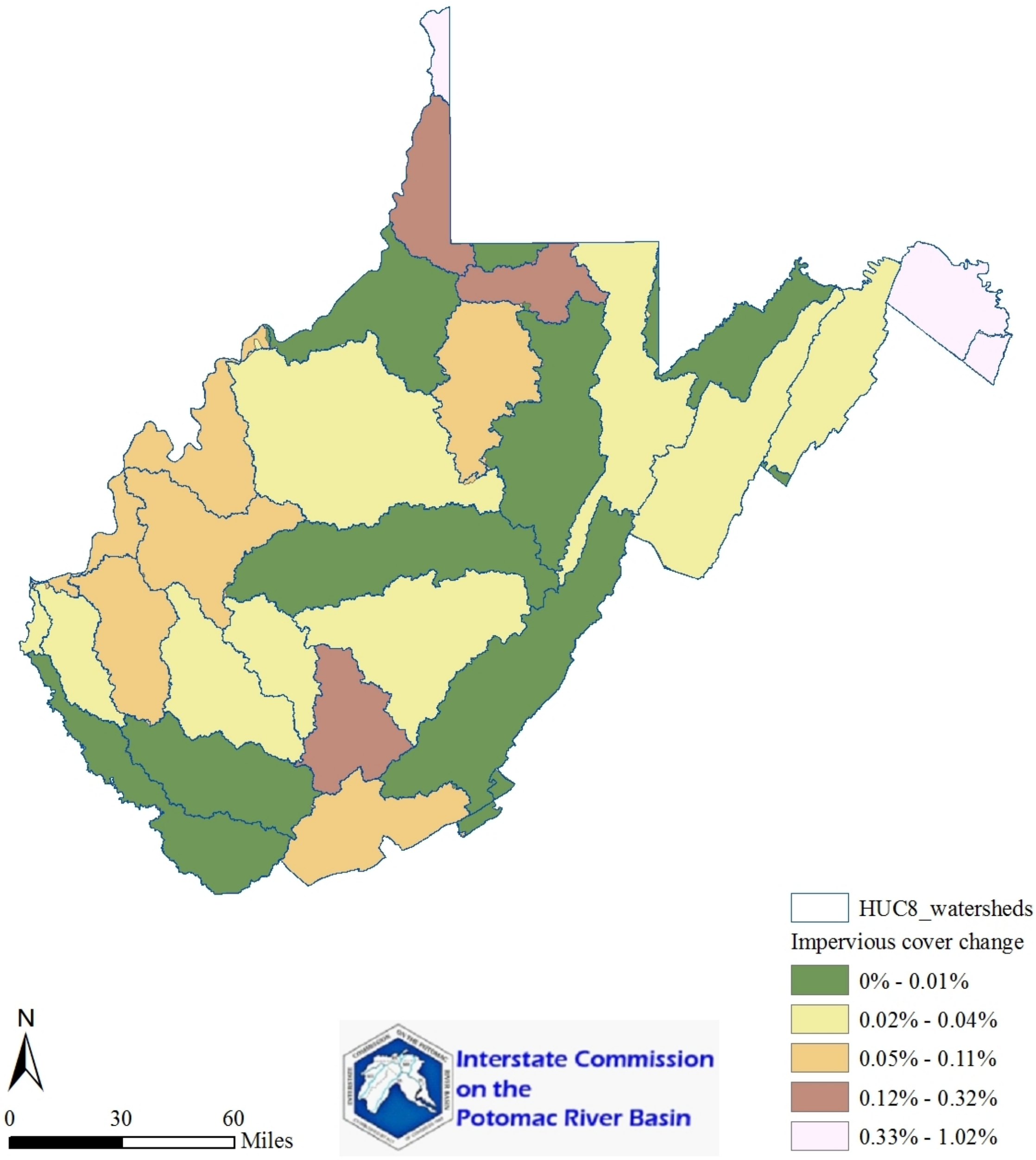


Figure 4. Change in impervious cover percent NLCD 2001 – 2006 by HUC8 watershed.



2.2 Dams

Dams impound water during high-flow periods for subsequent in-stream or off-stream uses. In performing this function, they alter the natural flow regime by reducing the high-flow peaks and artificially increasing flows during subsequent dam releases (Richter and Thomas 2007). Regulatory conservation releases of water from the dams are designed to protect the downstream aquatic ecosystem. These releases require a minimum flow during periods of drought or other extreme low-flow conditions.

There are 804 dams listed in the DEP NC_Dams dataset[4]. Dams are designed to impound water for a purpose. Some purposes inherently have a larger impact on flow during low flow conditions. Many of the dams in the dataset do not have a purpose listed (273) or do not have a watershed listed (257). The purposes of the dams included in this analysis range from flood control to water supply, with many dams having more than one listed purpose. The location of the dams included are shown in **Figure 5**. In West Virginia, dams for flood control, hydroelectric, water supply, and recreation purposes potentially have deleterious effects on low-flow conditions. This section focuses on those dams. The dams not included are not expected to impact low flows because their operation does not significantly impact the flow of a natural stream. **Table 2** includes the number of dams in each of the watersheds by purpose.

Flood control dams are designed to reduce downstream flooding caused by large rainfall events, (e.g. a 100-year, or six-hour duration storm). The stormwater is stored and later released slowly during lower streamflow conditions. By releasing during natural low-flow conditions, the natural flow variability required for a healthy aquatic ecosystem may be reduced. There are 181 dams with flood control listed as one of their purposes in the DEP NC-Dams dataset.

Hydroelectric power is generated using the kinetic energy of falling water to turn a turbine connected to a generator. There are two types of dams used for generating electric power, conventional dams and run-of-river dams. Conventional dams are structures that are able to store large amounts of water to generate electrical power at later time. Streamflow below conventional dams is dependent on the operational discharges of the power plant. Run-of-river dams are less likely to impact low flows as they have much less storage behind the dam, intercept only a portion of the river’s flow, and minimally regulate natural flows. There are four dams used for hydroelectric power generation on rivers in West Virginia. There are two large conventional hydroelectric dams, one in the Cheat River watershed and one in the Lower New River watershed. The other two dams are run-of-river dams on the Kanawha River and the Shenandoah River.

Water supply dams provide a dependable source of potable water by capturing significant portions of high-flow events. High flows and low flows can be impacted by the presence of water supply dams (Richter and Thomas 2007). Low flows are impacted because water is removed directly from the reservoir or immediately downstream of the dam removing this water from the stream. There are a total of 128 water supply dams listed in the DEP NC-Dams dataset, with 16 in the West Fork River watershed, the largest number in any watershed in West Virginia.

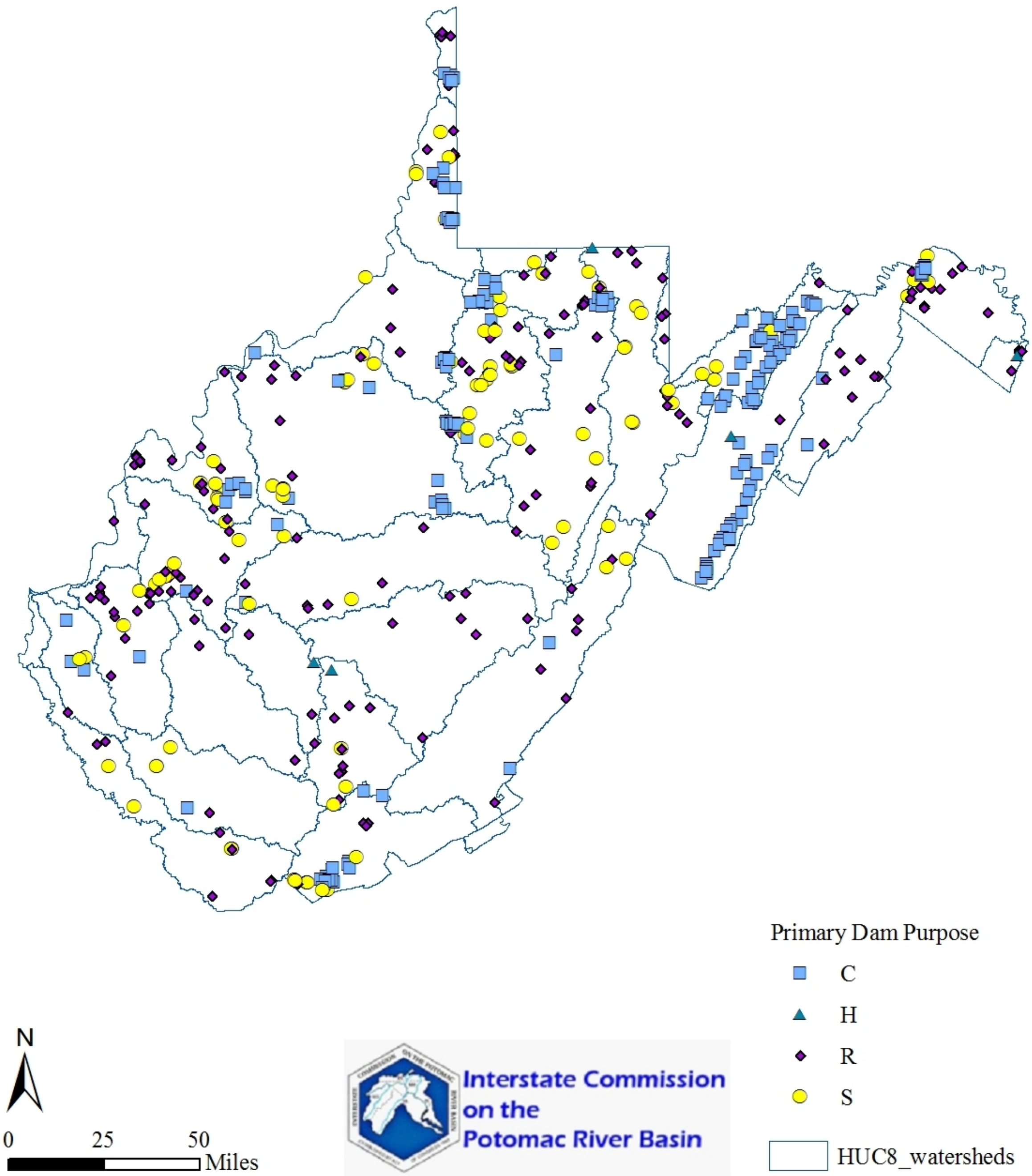
Recreation dams have similar operating protocols as water supply dams. They capture water during high-flow periods and store it to maintain a pool for recreational purposes. Releases from the dam will occur with additional inflows into a full reservoir. During dry periods, usually also low-flow periods, the reservoir level is likely to be lower due to lack of inflow and increased evaporation. Regulatory conservation releases are helpful to protect the aquatic ecosystems downstream of recreation dams. Recreation is listed as one of the purposes for 236 dams or 43 percent of dams in West Virginia (DEP NC-Dams dataset).

[4] GIS dataset of Non-Coal dams in West Virginia, provided by DEP, NC_Dams.shp, accessed 1/10/2013

Table 2. Number of dams with potential low-flow impacts by watershed.

HUC8	Flood Control	Water Supply	Hydroelectric	Recreation
South Branch Potomac	29	0	0	3
North Branch Potomac	42	7	0	2
Cacapon	2	0	0	10
Potomac Direct Drains	8	5	0	13
Shenandoah Hardy	0	0	0	0
Shenandoah Jefferson	0	0	1	4
James	0	0	0	0
Tygart Valley	1	6	0	13
West Fork	19	16	0	20
Monongahela	14	9	0	8
Cheat	1	10	1	11
Dunkard	0	1	0	0
Youghiogheny	0	0	0	3
Upper Ohio North	6	0	0	5
Upper Ohio South	12	5	0	9
Middle Ohio North	0	0	0	3
Middle Ohio South	7	9	0	21
Little Kanawha	10	14	0	13
Upper New	15	12	0	6
Greenbrier	3	4	0	8
Lower New	0	3	1	8
Gauley	2	2	0	7
Upper Kanawha	0	0	1	4
Elk	1	4	0	10
Lower Kanawha	3	9	0	25
Coal	0	0	0	3
Upper Guyandotte	1	3	0	2
Lower Guyandotte	2	2	0	13
Tug Fork	0	5	0	8
Big Sandy	0	0	0	0
Lower Ohio	0	0	0	1
Twelvepole	3	2	0	3
Total	181	128	4	236

Figure 5. Flood control (C), hydroelectric (H), recreation (R), and public water supply (S) dams in West Virginia.



The MPRWA final report found that impoundments may slightly increase the 7Q10, a low-flow metric defined as the lowest seven-day average flow likely to occur once every ten years; increase the duration of low pulses; and may impact median flows sometimes increasing or decreasing the levels (U.S. Army Corps of Engineers et al. 2012). The study found a moderate link between an increase in the duration of low pulses and impoundments and withdrawals; however, it was difficult to statistically evaluate the impacts on flow alteration because there are so few large dams in the Potomac River basin.

2.3 Surface Mining

Several studies have compared the streamflow characteristics in mined and un-mined watersheds. Surface mining activities include removal of layers of rock, "overburden" overlying coal seams in order to gain access to the coal, a process also known as "mountaintop removal" mining. Associated with surface mining (and to a lesser degree with underground mining) are valley fills. Valley fills are valleys usually adjacent to surface mining sites where the removed overburden is placed. These valleys frequently contain ephemeral or small first-order streams. Studies found mean monthly flows during normally dry periods, 90 percent duration flows[5], and daily flows during low-flow periods greater in streams below valley fill than in un-mined watersheds. They also found that peak flows resulting from intense storms are greater below valley fills. High flows resulting from less-intense storms, on the other hand, are frequently (but not consistently) lower below valley fills than in un-mined watersheds (EPA 2011; Messinger 2003; Messinger and Paybins 2003; Wiley and Brogan 2003; Wiley et al. 2001).

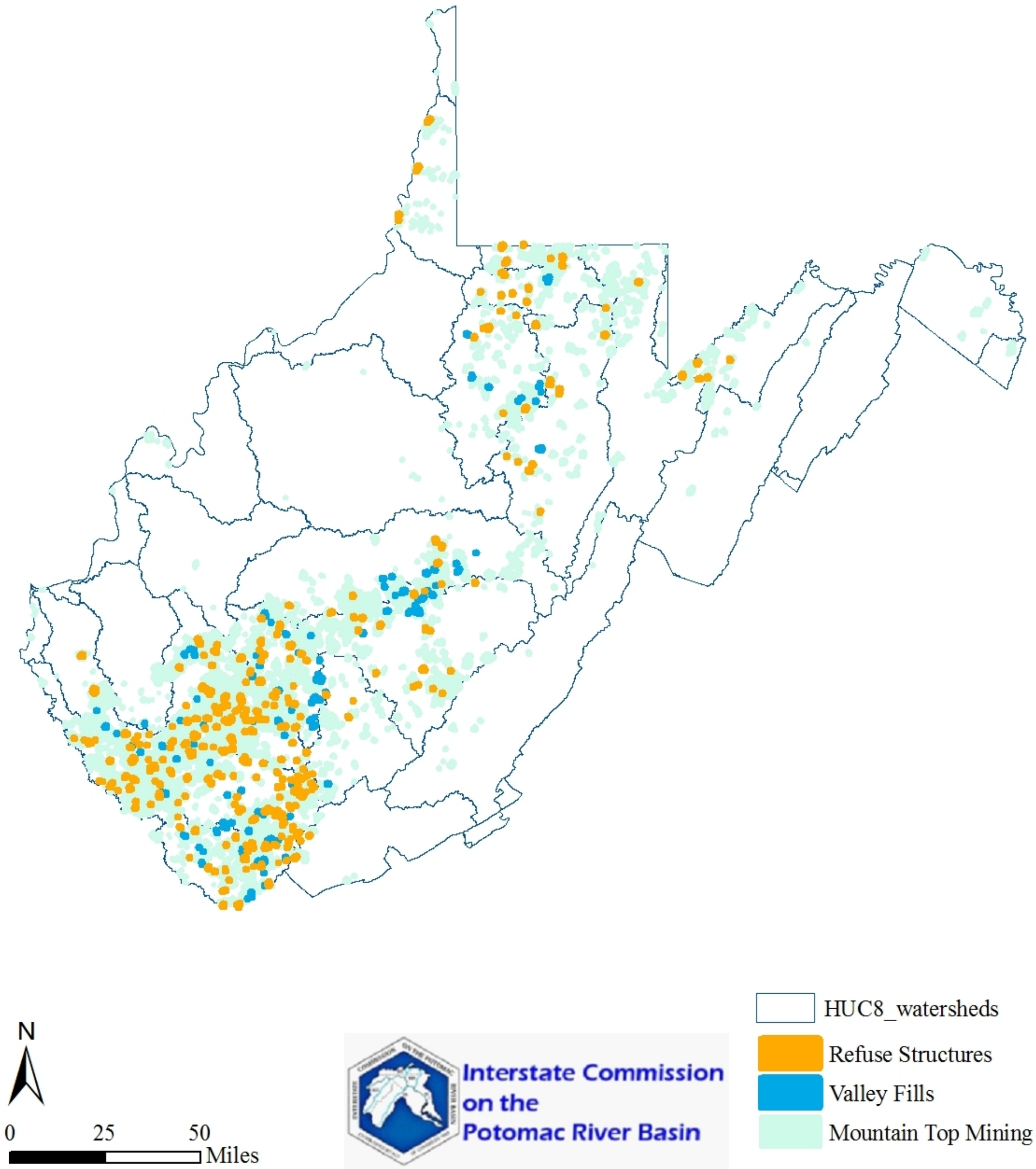
A geographic information system (GIS) dataset of permits for surface mining and related activities was downloaded from the DEP web site Technical Applications and GIS Unit (TAGIS[6]). The area of surface mining identified as either active or potentially active (personal comm., N. Schaer, 1/18/2013) was totaled in GIS for each HUC8 (**Table 3)**. A map of the approximate location of surface mining activities, valley fills, and refuse pile structures is shown in **Figure 6**. This dataset also contains the area of quarries within the state under the assumption that quarries could have similar impacts on nearby streams as other surface mining activities. Most valley fill refuse pile areas are part of the surface mining activities and are located within the surface mine permit area. There are some valley fill and refuse pile areas located outside of permitted surface mine areas, due to lack of available space within the permitted mine area or for other operational reasons. These extra-surface mine valley fills and refuse areas were also provided in GIS datasets from the DEP TAGIS web site. The total of their area is also included in **Table 3**. The last column of **Table 3** is the percent of the total HUC8 area that is under surface mine permit area, valley fill, or refuse pile areas. The greatest total area of these surface mining activities in any HUC8 watershed as a percentage of the watershed area was 18 percent in the Coal watershed.

[5] The 90% duration flow is the streamflow equaled or exceeded at a site 90% of the time, a measure of baseflow.
[6] WVDEP Technical Applications & GIS Unit, http://tagis.dep.wv.gov/, accessed 01/17/2013.

Table 3. Total area (sqmi) of active surface mining and related activities by HUC8, percent of the total HUC8 area, and area of valley fills outside other surface mining areas.

HUC8	Surface Mining Activities	Extra-Surface Mine Valley Fills	Extra-Surface Mine Refuse Structures	Percent of HUC8 Area
South Branch Potomac	1.6	0	0	0.1
North Branch Potomac	9.6	0	0	1.6
Cacapon	0.0	0	0	0.0
Potomac Direct Drains	3.3	0	0	0.6
Shenandoah Hardy	0.0	0.06	0.05	0.6
Shenandoah Jefferson	3.6	0	0	3.5
James	0.0	0.1	0.09	0.3
Tygart Valley	15.3	0.06	0.05	1.1
West Fork	9.4	0.22	0	1.1
Monongahela	16.3	0.1	0.09	3.6
Cheat	8.2	0	0	0.6
Dunkard	2.3	0	0.07	2.1
Youghiogheny	0.2	0	0	0.3
Upper Ohio North	1.4	0	0	1.1
Upper Ohio South	5.1	0	0.04	0.9
Middle Ohio North	0.2	0	0	0.0
Upper Ohio South	1.8	0	0	0.3
Little Kanawha	0.1	0	0	0.0
Upper New	2.1	0	0.03	0.3
Greenbrier	2.4	0	0	0.1
Lower New	3.1	0.06	0.07	0.5
Gauley	59.3	0.49	0.08	4.2
Upper Kanawha	74.8	0.36	0.04	14.3
Elk	46.4	0.3	0.03	3.0
Lower Kanawha	1.8	0	0	0.2
Coal	156.6	0.19	0.25	17.5
Upper Guyandotte	79.1	0.31	1.29	8.5
Lower Guyandotte	19.5	0.01	0	2.6
Tug Fork	106.4	0.62	0.59	11.5
Big Sandy	0.2	0	0	0.3
Lower Ohio	0.4	0	0	0.2
Twelvepole	25.1	0.04	0	5.6

Figure 6. Map of surface mining and related activities (size is exaggerated for improved visibility).



2.4 Withdrawals and Discharges

Groundwater withdrawals can impact nearby streamflows by reducing the natural groundwater discharge that contributes a major portion of streamflow during low-flow conditions, especially in headwater streams. Surface water withdrawals directly impact streamflows by diverting some of the natural flow to off-stream uses. Discharges to streams have the opposite effect, adding water to natural flows. The result is a reduction in low flows and an increase in high flows.

A database of large quantity water users from groundwater and surface water sources was provided by DEP. **Table 4** includes the total annual groundwater withdrawals, surface water withdrawals, and surface water discharges, in million gallons per year (Mgal/y) listed by HUC8 watershed (**Figure 7**). This data does not include withdrawals or discharges that are inactive; withdrawals and discharges for hydroelectric facilities (as they remove no water from the stream and only use the kinetic energy of the water to generate power); or discharges to other than surface water bodies, such as underground injection wells. The total annual withdrawals vary greatly between the watersheds with a maximum of 655 Mgal/y in one watershed and 0 Mgal/y shown for another. Total groundwater withdrawals are less than 2 percent of surface water withdrawals and total annual discharges are 85 percent of total annual withdrawals.

The MPRWA (U.S. Army Corps of Engineers et al. 2012) found that withdrawals reduced annual mean, median and August median flows, increased the flashiness and fall rate of flows, increased the extreme low flow frequency, decreased the high flow index metric and the high flow duration metric, and caused a slight decrease in the 3-day maximum, 3-day minimum flows, number of reversals in flow change, high pulse frequency, and a slight increase in the duration of low flow pulses (U.S. Army Corps of Engineers et al. 2012, Table 4 Appendix G). Discharges were found by this study to:

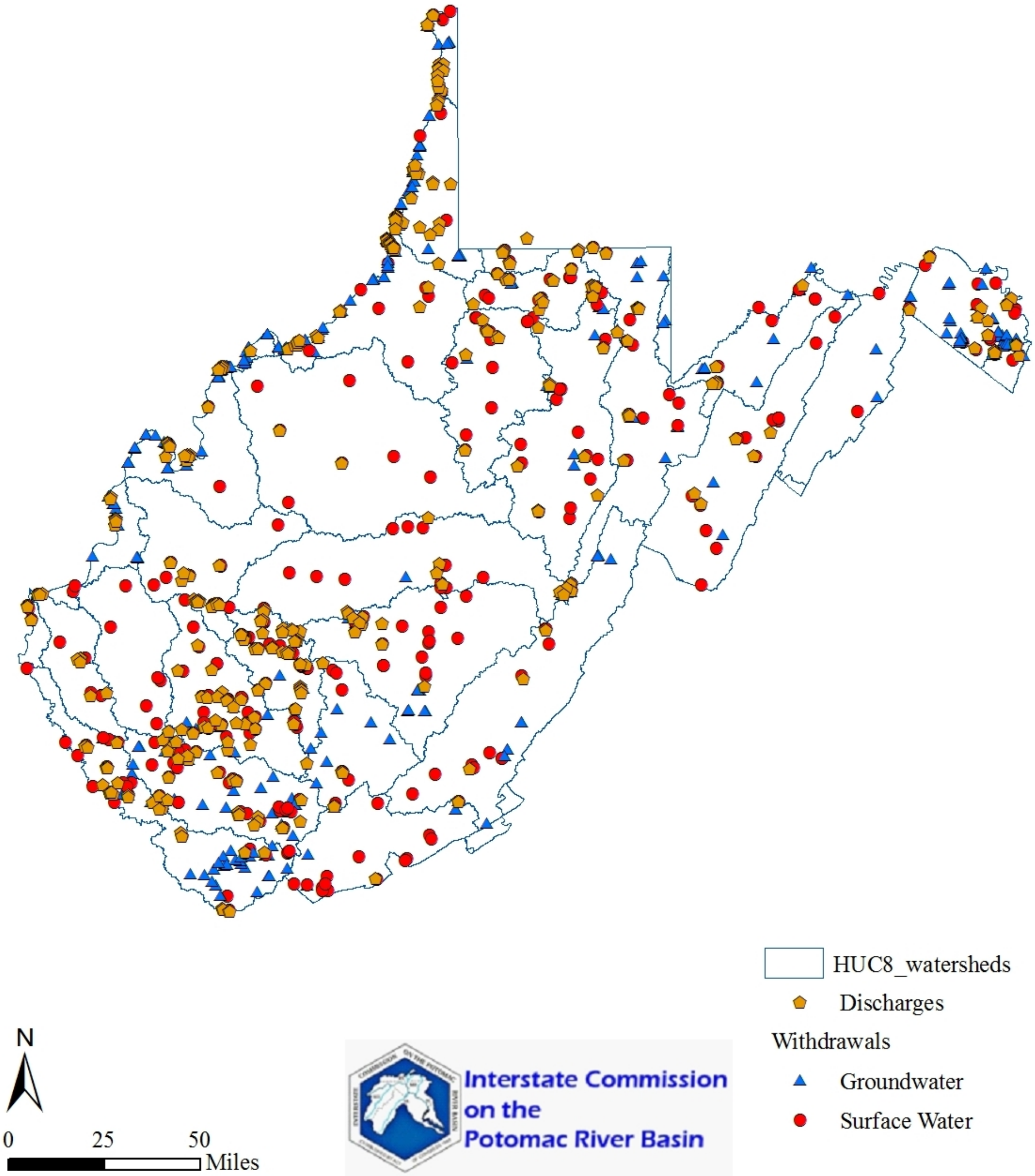
- increase annual mean, annual median, August median, and 3-day minimum flows;
- decrease flashiness, low pulse duration;
- slightly decrease extreme low flow frequency; and
- slightly increase high flow duration index metric.

Comparing West Virginia withdrawals to the natural flows will enable the evaluation of the potential impact on low flows. Watershed modeling similar to that performed for the MPRWA study could provide an evaluation of the magnitude of impacts represented by these withdrawal and discharge volumes.

Table 4. Active ground and surface water withdrawals and discharges (Mgal/y) to surface water bodies by HUC8, not including hydroelectric facilities.

HUC8	GW withdrawals	SW withdrawals	SW discharges
South Branch Potomac	23	4,306	2,338
North Branch Potomac	125	403,834	12
Cacapon	25	44	0
Potomac Direct Drains	6,239	4,098	3,649
Shenandoah Hardy	0	0	0
Shenandoah Jefferson	162	177,757	159,059
James	0	0	0
Tygart Valley	285	5,976	6
West Fork	27	17,372	4,114
Monongahela	33	43,566	38,041
Cheat	198	655,482	563,353
Dunkard	0	598	210
Youghiogheny	101	0	0
Upper Ohio North	1,435	64,155	21,543
Upper Ohio South	2,387	176,030	179,773
Middle Ohio North	7,413	79,408	74,935
Upper Ohio South	9,474	306,434	331,081
Little Kanawha	0	1,084	55
Upper New	68	2,740	140
Greenbrier	820	1,371	415
Lower New	483	4,101	105
Gauley	542	1,342	779
Upper Kanawha	461	154,169	186,024
Elk	122	12,140	7
Lower Kanawha	0	81,501	73,030
Coal	1,002	4,566	3,231
Upper Guyandotte	1,084	1,543	855
Lower Guyandotte	0	1,404	0
Tug Fork	1,052	2,289	37
Big Sandy	0	959	104
Lower Ohio	894	4,651	404
Twelvepole	3	482	248
Total	34,458	2,213,403	1,643,549

Figure 7. Map of surface and ground water withdrawals and surface discharges.



3 Summary

Humans have altered the natural environment in West Virginia through a myriad of activities including, but not limited to, uses of the lands, dams, mining, and withdrawals and discharges. These activities can impact aspects of the natural environment that are depended on for human survival. Low-flow conditions are one factor that can be altered by human activities. Maintaining the natural resilience in the system during low-flow conditions will assist in continuing to meet the human and ecosystem needs.

The MPRWA (U.S. Army Corps of Engineers et al. 2012) investigated the relationships between streamflow alteration and a number of anthropogenic activities including percent urban and agricultural areas in a watershed and percent impoundments, withdrawals, and discharges as functions of median flow volume. Human activities were found to negatively impact low-flow conditions in streams to varying degrees.

Example relationships from that study are provided in **Table 5**. The 3-day minimum is the average of each year's lowest 3-day moving average of daily flow, normalized by watershed area. Large withdrawals decrease levels of the low magnitude flow metric 3-day minimum because less water is available in-stream; large discharges increase levels by adding water, albeit with different water quality. Levels of the 3-day minimum are lower in areas with greater than roughly 25-30 percent urban cover although this threshold is often confounded by withdrawals and discharges. On the other hand, increasing agricultural area increases low flows, particularly 3-day minimum because of lower evapotranspiration rates under crop cover (simulated current conditions) when compared to forest (simulated predevelopment condtions). Decreasing evapotranspiration makes more water available for streamflow. Simulated low flows below the major impoundments in the Middle Potomac study area suggest that flow management may serve to increase minimum flows. The extreme low flow frequency is the frequency of extreme low flow events in a year, where daily flow is in the lowest tenth percentile of all the low flows. Significant withdrawals increase the frequency of extreme low flows because less water is available in-stream. Discharges decrease the frequency of extreme low flows by supplementing available water. Increases in the amount of agricultural areas do not appear to influence the frequency of extreme low flows. Urbanization, however, increases the frequency of extreme low flows due to the system becoming more "flashy" with higher high and lower low flows. Low pulse duration is the median of the annual average number of consecutive days per year that daily flow is below the tenth percentile. The duration of low pulses is shorter in highly urban areas but longer in watersheds with large withdrawals. Increasing the duration of low pulses can be moderately associated with increasing withdrawals and impoundments.

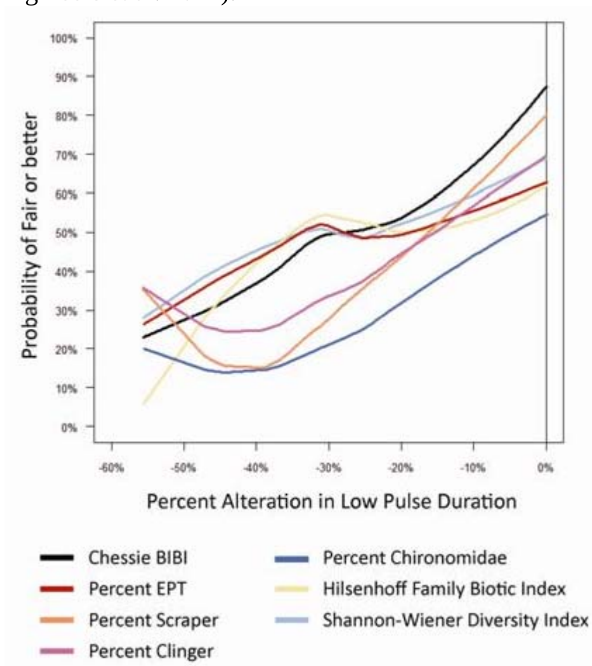
Overall, the strongest relationship between anthropogenic activities, flow alteration, and ecological response was found to be with an increase in impervious cover. The greatest increase in impervious cover in any West Virginia HUC8 watershed was one percent, likely resulting in increased flashiness, increased frequency of extreme low flows, decreased duration of low pulses, and an increase in the number and magnitude of high-flow events.

Table 5. Changes in select low-flow metrics and associated changes in anthropogenic activities (modified from U.S. Army Corps of Engineers et al. 2012). 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 not enough data were available.

Flow metric	% Urban	% Agriculture	% Impoundments	% Discharges	% Withdrawals
3-day minimum flow	=	▲		▲	▽
Extreme low flow frequency	▲	=		▽	▲
Low pulse duration	▼		△	▼	△

The alteration in low flow characteristics associated with the anthropogenic activities described above can negatively affect ecosystem health. The MPRWA examined the impacts of alteration in flow metrics on stream health. That study evaluated a myriad of flow metrics (e.g. 3-day minimum flow, extreme low frequency, and low pulse duration explained above) and biological metrics (examples provided below). As an example, the impacts of anthropogenic alterations in low pulse duration on a number of biological metrics are explored in **Figure 8**. Biological metrics represented in this plot include the Chesapeake Bay Benthic Index of Biologic Integrity (or Chessi BIBI which is the average of scores of five bioregion-specific, family-level metrics), the percent EPT (or the percent of individuals that are Ephemeroptera, mayflies), percent scraper (or the percent of individuals that are adapted for scraping periphyton from hard surfaces), percent clinger (or the percent of individuals adapted for clinging to hard surfaces), percent Chironomidae (or the percent of individuals that are Chironomidae, non-biting midges), the Hilsenhoff Family Biotic Index (an average of the family-level tolerance score of each individual), and the Shannon-Weiner Index (a measure of taxanomic diversity). Overall, ecological health represented by these metrics declines as the changes in low pulse duration become more severe (shown by the decreasing chance of having a fair or better status on the Y-axis as alteration in low pulse duration moves further away from zero on the X-axis). There are some differences in the shapes of the curves and increasing uncertainty at the outer bounds of the curves (the left side of the X-axis) create some bumps, but the overall trend is decreasing ecological health with increasing hydrologic alteration. Impacts of hydrologic alteration represented by other flow metrics on ecological health that were explored in the MPRWA show similar trends.

Figure 8. Flow alteration-ecological response relationships for positive alteration (increase) in low pulse duration (reprinted from U.S. Army Corps of Engineers et al. 2012). The Loess smoothed regression lines of the conditional probability plots are shown. “Fair” status of each biological metric is defined by the bioregion-specific thresholds. As alteration in low pulse duration increases (in the negative direction) for all biometrics shown, the probability of having a fair of better biological status decreases. For full information on interpreting this plot please see MPRWA Appendix H (U.S. Army Corps of Engineers et al. 2012).



The MPRWA results indicate that impacts to ecological health can be expected in West Virginia with alterations in low flow conditions. The magnitude and extent of the ecological impacts depends on the amount of hydrologic alteration and the drivers of the hydrologic alteration. The full suite of flow alteration – ecological response relationships in the MPRWA may prove useful to land and water planning efforts in the state because they quantitatively describe how flow alteration and ecological health are related for a number of flow and biological metrics. A West Virginia (and perhaps watershed) specific decision-making process will be needed to determine what types of ecological impacts are acceptable and, therefore, what extent of hydrologic alteration will be tolerated.

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