AN ANALYSIS OF IMPERVIOUS AREA INCREASE VS. POPULATION GROWTH IN THE CHESAPEAKE BAY WATERSHED BETWEEN 1990 AND 2000

ADDENDUM #1

MARCH 9, 2010
WSSI #21859.01

AUTHORS:

JENNIFER A. BROPHY-PRICE, P.E.
BEN SLATER, GISP
MICHAEL S. ROLBAND, P.E., P.W.S., P.W.D.

5300 Wellington Branch Drive • Suite 100 • Gainesville, VA 20155 • Phone 703.679.5600 • Fax 703.679.5601
Contactus@wetlandstudies.com • www.wetlandstudies.com

AN ANALYSIS OF IMPERVIOUS AREA INCREASE VS. POPULATION GROWTH IN THE CHESAPEAKE BAY WATERSHED FROM 1990-2000

ADDENDUM #1

INTRODUCTION

This report outlines additional efforts we have undertaken to try to explain our observations regarding the impervious area increase vs the population increase in the Chesapeake Bay watershed. It is an addendum to the white paper of the same name, dated February 23, 2010.

EXECUTIVE SUMMARY

While we have been unable to reach a definitive conclusion regarding our results (except that the Phase 5.2 model does *not* corroborate the claim that impervious surfaces in the watershed increased by 41% between 1990 and 2000), our additional research below has uncovered three points of interest. Specifically, it appears that:

1. The variation between the RESAC data (the basis of the 41% impervious area increase claim) and the Phase 5.2 model data increases with population density. 1990 RESAC data is consistently lower than the Phase 5.2 model data, and 2000 data is consistently higher. This means that, in more populous areas, the perceived percent change is higher (on average) than in less populous areas.

2. The RESAC layers show impervious areas artificially increasing, or "bleeding," between 1990 and 2000, in locations which showed no physical change in imperviousness based on aerial photos.

3. All RESAC cells showing impervious area in 1990 show the same impervious area in 2000, which indicates that all impervious area increases come from greenfield development, rather than redevelopment.

ADDITIONAL IMPERVIOUS AREA RESEARCH

To begin this effort, we downloaded the following files (imperviousness data from the University of Maryland's Regional Earth Sciences Applications Center (RESAC)) from the project FTP site at ftp://ftp.chesapeakebay.net/Modeling/GIS/landuse/all_landcov.zip:

- umdimp90_v131;
- umdimp2k_v131; and
- UMD-Imperv-Version 1.3 Changes.doc**.**

Our understanding[1] is that these two files (and documentation) represent the 1990 and 2000 impervious area coverage for the Chesapeake Bay watershed and were used to initially calculate

[1] "All_landcov.zip" also includes metadata text files showing that these layers match the description in Goetz, et al, 2004, Integrated analysis of ecosystem interactions with land use change: the Chesapeake Bay watershed (http://www.geog.umd.edu/resac/lc2.html), which is cited as the reference for the chart showing the 41% impervious area increase (http://www.chesapeakebay.net/status_population.aspx?menuitem=19842, Analysis and Methods).

the impervious area increase. In an effort to replicate this calculation to use as a starting point, we calculated the average percent imperviousness for each cell within the watershed and multiplied it by the area of the watershed. We arrived at an impervious area increase of 44.8%, which is approximately 10% higher than the 41% claimed for the Bay-wide watershed, as shown in Table 1, below, but is close enough (considering the scale of the study) to suggest that we are using the same data source as the original claim.

Data Source	Watershed Area (acres)	Impervious Acres (1990)	Percent Impervious (1990)	Impervious Acres (2000)	Percent Impervious (2000)	Increase (1990-2000)
chesapeakebay.net[2]	±40,900,000	602,766	---	848,727	---	41%
RESAC	41,168,527	624,226	1.5%	903,970	2.2%	44.8%
Phase 5.2 Model		683,629	1.7%	780,785	1.9%	14.2%

Table 1. Impervious area analysis

Because our overall impervious area calculation above resulted in a similar percent increase as the website claim, we chose several (26) counties and cities in Virginia and Maryland to analyze more closely to see if there is a pattern in the increases that isn't readily apparent at the overall watershed scale. We calculated the impervious surface acreages for 1990 and 2000 based on the RESAC data for individual land-river segments[3] using the same methodology described above. We also extracted model input values[4] for IMH (high-density impervious) and IML (low-density impervious) from 1987, 1992, 1997, and 2002 for each land-river segment, and used those values to calculate IMH and IML values for 1990 and 2000[5]. The results of this comparison are shown in Appendix A, which consists of an individual chart and table for each county/city showing impervious area growth (based on RESAC data and Phase 5.2 model data) and population growth between 1985 and 2008. We also included recent (2005-2008) GIS vector data for jurisdictions where such data was readily available (the counties of Arlington, Fairfax, James City, and Loudoun and the City of Alexandria)[6] to see if the RESAC and Phase 5.2 impervious surfaces correlate with current GIS information. Appendix A also includes a summary table showing the RESAC and Phase 5.2 model impervious area increases for the selected counties, along with the ratio of impervious area increase to population increase.

In the majority of counties that we looked at, the 1990 RESAC estimate is lower than the Phase 5.2 model estimate, while the 2000 RESAC estimate is higher than the Phase 5.2 model estimate. (This observation is consistent with the overall RESAC impervious area increase estimate that is 5 times greater than the Phase 5.2 model estimates.) To determine if there is a watershed-wide pattern between the RESAC data and the Phase 5.2 model data, we graphed population density (in people per acre) against the difference in percent impervious surface between the two data sources for each of the 203 jurisdictions (cities and counties) throughout the Bay watershed. In cases where a jurisdiction is only partially contained within the Bay watershed, the entire county (including the portion outside the watershed) was used for the calculations. Water bodies (as

[2] http://www.chesapeakebay.net/impervioussurfaces.aspx
[3] ftp://ftp.chesapeakebay.net/Modeling/GIS/model_gis_segs/GIS_GISOWNER_P5_RiverSegs_July07.shp.zip
ftp://ftp.chesapeakebay.net/Modeling/GIS/model_gis_segs/GIS_GISOWNER_P5_LandSegs_July07.zip
[4] ftp://ftp.chesapeakebay.net/Modeling/phase5/data/model_inputs/landuse
[5] Using simple linear interpolation.
[6] GIS vector data was obtained directly from the individual counties listed here.

defined in the 2000 land-use GIS layer) were subtracted from the total acreage of each jurisdiction so the results would not be skewed by jurisdictions containing large bodies of water. See Chart 1, below.

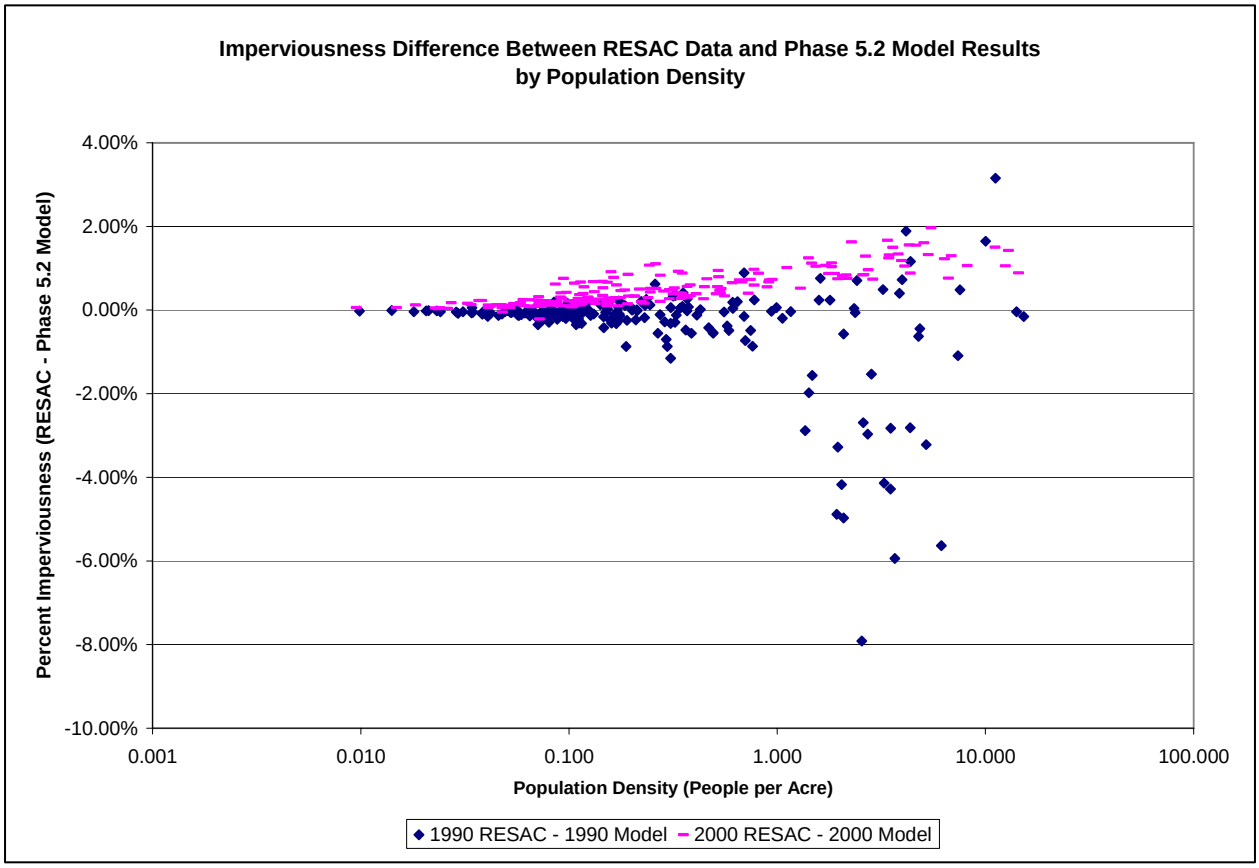


Chart 1. Imperviousness Differences Between RESAC Data and Phase 5.2 Model Results

Chart 1 shows that, throughout the Chesapeake Bay watershed, 1990 RESAC data is almost consistently lower than the Phase 5.2 model results, while the 2000 data is consistently higher. The 1990 difference is also greater in magnitude than the 2000 difference, especially in areas of high population density. In fact, the chart indicates that the discrepancies between the RESAC data and the Phase 5.2 model results tend to increase with increased density. (This is opposite of one suggestion that was posed to us that the impervious area in the Phase 5.2 model simply does not include imperviousness in non-urban land uses.)

We also looked to correlate the impervious area variation with population, population growth, percent impervious area, and impervious area growth, but we did not see a trend based on casual observation. Among the data we gathered, the only trend appears to correlate impervious area variation with population density, as seen above in Chart 1.

Our GIS vector data analysis indicates that the Phase 5.2 impervious areas are within approximately 10% of the GIS vector data in all cases except for James City County (in which case the Phase 5.2 model imperviousness is 50% lower than the current GIS imperviousness calculation.) The RESAC data is harder to correlate with the GIS data because of the time

between the last RESAC data point and the GIS vector data, but they also seem to correlate fairly well, at least visually. This general precision between methods is good to note, because it appears that the RESAC and model estimates are at least reasonably accurate based on up-to-date GIS information. The GIS vector data does not, however, give us any indication of which growth trend (RESAC vs. Phase 5.2 model) is more accurate because the available GIS data does not extend far enough into the past.

Finally, to try to understand the trend observed in Chart 1, we looked at land-river segments where the RESAC data indicates a large increase in impervious surface but the model inputs indicate little or no change. Richmond, Virginia, shows such a trend, so we chose three study areas to analyze in the Richmond area. We overlaid the 1990 and 2000 RESAC layers on 1981, 1994, and 2004 aerial photographs[7] to give us a baseline for each area. The photos help us generally interpret the impervious surfaces of each RESAC layer and give us an idea about what impervious areas may or may not have changed during the 1990-2000 time period. (See Appendix B).

Appendix B1: Richmond, Virginia (Overall)

The Richmond, Virginia, region shows significant increases in impervious area according to the RESAC layers but very little increase in the 5.2 model. This region also shows little to no population growth from 1990 to 2000.

We chose to focus on the portion of Richmond that intersects River Segment JL7_7070_0001. Most of this area appears to consist of residential and urban developments that were established prior to 1990. This assumption is corroborated by a photo dated March 11, 1994, which shows the presence of large trees and a dense rectangular road network in the residential areas. Areas which have high impervious surface coverage according to the 1990 RESAC data appear to be shopping centers and urban downtown centers. Comparing the 1994 and 2004 photos for this area (not shown in Appendix B1 for clarity due to the size of the study area) shows very little obvious change, with the exception of one new shopping center (approximately 40 acres). However, the RESAC impervious layers indicate an overall increase of 25% in impervious surface for this area.

	Impervious Area (acres)		Increase	
	1990	2000	Acres	Percent
Phase 5.2 Model	2,738	2,765	26	1.0%
RESAC	2,395	3,000	605	25.3%

Table 2. Summary of Richmond, VA, JL7_7070_0001

Appendices B2-B4 (explained more fully below) show examples of impervious surfaces (based on the RESAC impervious layers) appearing to "bleed" into pervious surfaces between 1990 and 2000, when they should theoretically show no change.

[7] Because this is an unfunded analysis, we used readily-available photographs rather than expending the time and money to obtain 1990 and 2000 images.

Appendix B2: Richmond, Virginia (Study Area 1)

Study Area 1 consists of residential neighborhoods in Richmond in the western portion of the study area and a large cemetery in the eastern portion of the study area. Images 1 and 2 (impervious data in 1990 and 2000) show similar patterns of imperviousness within the residential neighborhoods, but Image 3 (showing the change in imperviousness between 1990 and 2000) reveals a pattern of increased imperviousness along the boundary between the residential section and within the cemetery. The 1981 aerial photo in Image 1 shows that many of the roads and houses along the edge of the development were in place prior to 1990, indicating that the there should be no "bleed" in imperviousness; it also indicates that the 1990 RESAC data may have "missed" impervious areas along the edges of existing development.

Appendix B3: Richmond, Virginia (Study Area 2)

Study Area 2 is centered on the Powhite Parkway Bridge over the James River in Richmond. The 1990 RESAC layer[8] shows the bridge as a line of cells with high values for impervious surface (as expected). However, the bridge appears wider based on the 2000 RESAC layer. According to the Richmond Metropolitan Authority website[9], the bridge was widened in 1987-1988 and resurfaced in 1996 without widening[10]. (The bridge was, however, restriped in 1996 with narrower lanes to add one more lane of capacity.) Thus, the area of impervious surface for this feature should remain constant from 1990 to 2000, rather than increasing (significantly) as the RESAC layers indicate.

Appendix B4: Richmond, Virginia (Study Area 3)

Study Area 3 is just northeast of Study Area 2 and centers on a large rectangular structure (which is indicated on the Wikimapia.org website to be a reservoir, although there is some conjecture regarding its actual use.) Regardless, the 1981, 1994, and 2004 aerial photos indicates that the size and shape of the structure's impervious area have remained constant. The 1990 RESAC layer, however, appears to only show the structure's core as impervious, while the 2000 RESAC layer encompasses the entire structure. This again appears to be a "bleed" of imperviousness increase on the fringe of existing impervious cells, rather than a physical increase in impervious area.

This pattern seems to occur often throughout the RESAC dataset in locations with an abrupt transition from an area of high imperviousness to an area of low or no imperviousness. This could be an error with the RESAC dataset that results in an overestimation of the increase in impervious surfaces throughout the watershed. (This is not meant to imply that the higher impervious surface value from the 2000 data is

[8] The 1990 RESAC layer is overlain on a 1994 aerial photo, rather than a photo from 1981. This is because we know that the bridge did not change size between 1990 and 2000 and chose to use a photo with a closer date.
[9] http://www.rmaonline.org/facilities/powhite.html
[10] We also confirmed with VDOT and the Richmond Metropolitan Authority (via e-mail on March 4, 2010) that the bridge width did not increase between 1990 and 2000.

incorrect, just that the perceived *increase* is higher than it should be. Since the increase has been quoted extensively, it should be as accurate as possible.)

During the analysis of the 1990 and 2000 RESAC layers, we also noted a trend that can be described as "odd" at best, at least statistically. In the files we downloaded from the FTP site, every RESAC cell that has an impervious surface value greater than 0 in 1990 shows the exact same value in 2000. This would indicate that, throughout the Chesapeake Bay watershed, no surface[11] increased or decreased in impervious area between 1990 and 2000 and that all imperviousness increases came from greenfield development. Physically, this is unlikely (since redevelopment typically changes impervious area one way or the other), and statistically, it is nearly impossible. Even without physical changes in impervious area, a portion of the cells should show some sort of variation based on the inexact nature of the satellite imagery and reflectance analysis.

We have been unable to reach a definitive conclusion regarding our results, although we have noted three points of interest. Specifically, it appears that:

1. The variation between the RESAC data (the basis of the 41% impervious area increase claim) and the Phase 5.2 model data increases with population density. 1990 RESAC data is consistently lower than the Phase 5.2 model data, and 2000 data is consistently higher. This means that, in more populous areas, the perceived percent change is higher (on average) than in less populous areas.

2. The RESAC layers show impervious areas artificially increasing, or "bleeding," between 1990 and 2000, in locations which showed no physical change in imperviousness based on aerial photos.

3. All RESAC cells showing impervious area in 1990 show the same impervious area in 2000, which indicates that all impervious area increases come from greenfield development, rather than redevelopment.

We welcome further discussion on this topic; we understand that our analysis could be in error and we believe it is important to base claims (including our own) on the most accurate data.

L:\21000s\21800\21859.01\Admin\Correspondence\2010-02-26_ImperviousAreaVSPopulationGrowthMemo.doc

[11] Each cell is 30 meters by 30 meters, or approximately 970 square feet.

Appendix A: Impervious Area and Population Increase Comparison for Selected Counties and Cities in Virginia and Maryland

Summary Table

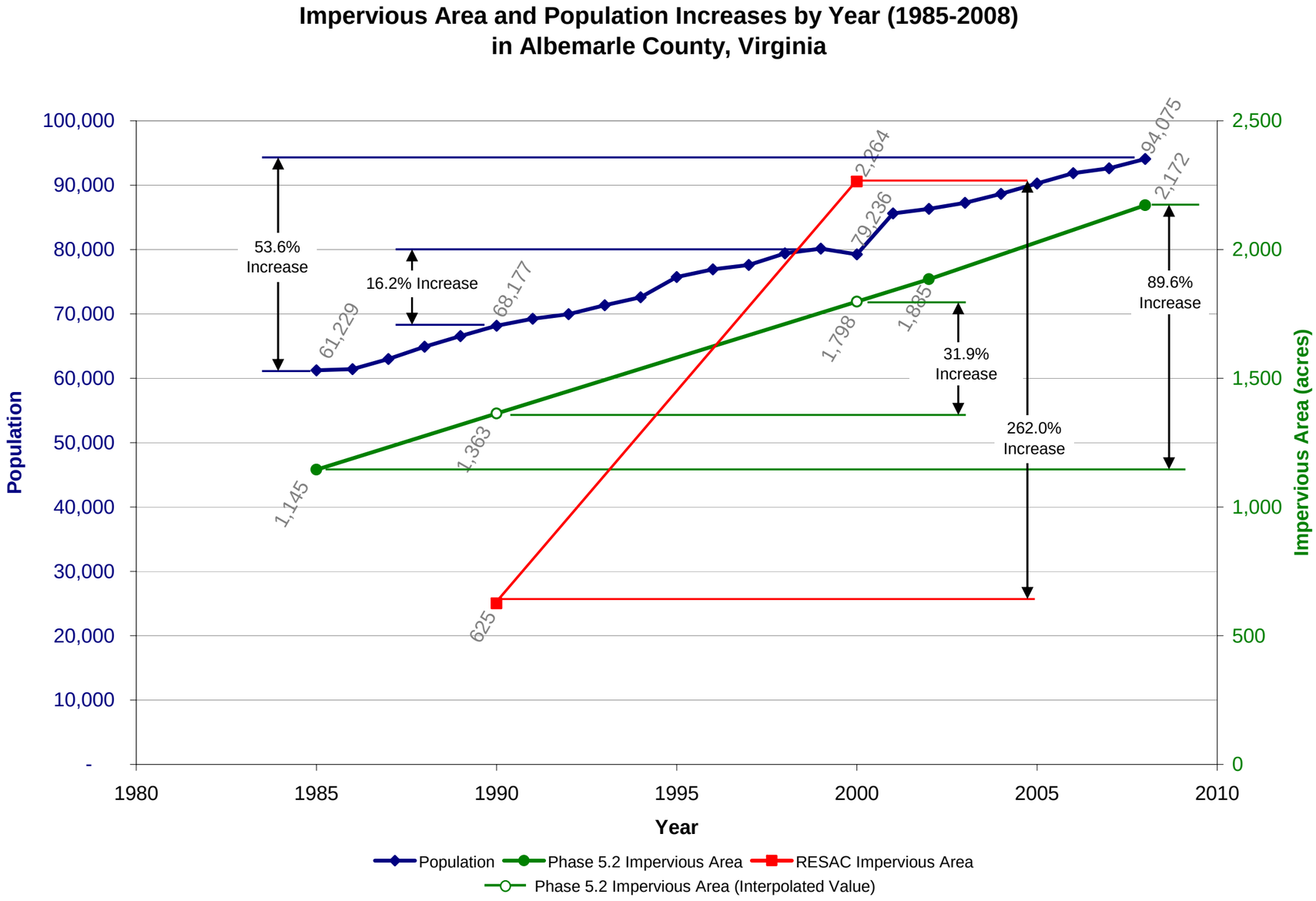
(* - indicates jurisdiction with GIS vector data used for comparison)

Appendix A: Impervious Area and Population Increase Comparison for Selected Counties and Cities in Virginia and Maryland

Summary Table

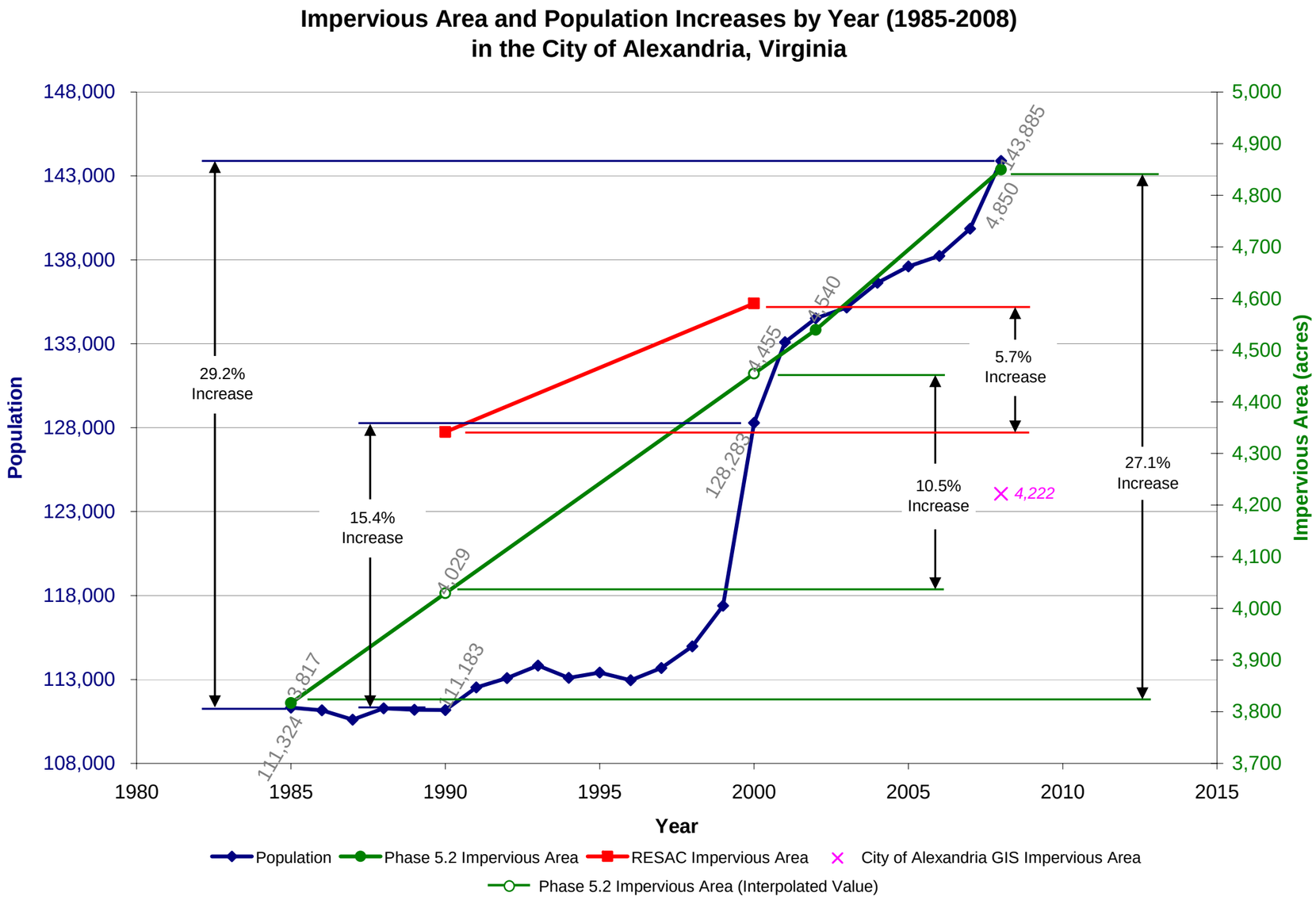
(* - indicates jurisdiction with GIS vector data used for comparison)

		1990 - 2000			1985 - 2008		
		Impervious Area Increase (%)	Population Increase (%)	Impervious Area Increase / Population Increase	Impervious Area Increase (%)	Population Increase (%)	Impervious Area Increase / Population Increase
Cheasapeake Bay Watershed	RESAC / Woods Hole Model	41.0	8.0	**5.1**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	14.2	10.3	**1.4**	38.4	26.5	**1.4**
Albemarle County, VA	RESAC / Woods Hole Model	262.0	16.2	**16.2**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	31.9	16.2	**2.0**	89.6	53.6	**1.7**
Alexandria City, VA	RESAC / Woods Hole Model	5.7	15.4	**0.4**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	10.5	15.4	**0.7**	27.1	29.2	**0.9**
Allegany County, MD	RESAC / Woods Hole Model	32.2	-0.02	**-1610.0**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	3.0	-0.02	**-150.0**	7.7	-5.3	**-1.5**
Anne Arundel County, MD	RESAC / Woods Hole Model	29.1	14.6	**2.0**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	18.9	14.6	**1.3**	47.9	29.5	**1.6**
Arlington County, VA	RESAC / Woods Hole Model	5.0	10.9	**0.5**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	5.9	10.9	**0.5**	11.1	27.0	**0.4**
Baltimore County, MD	RESAC / Woods Hole Model	16.9	9.0	**1.9**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	11.3	9.0	**1.3**	28.7	18.2	**1.6**
Charlottesville City, VA	RESAC / Woods Hole Model	63.3	11.3	**5.6**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	4.1	11.3	**0.4**	7.6	3.0	**2.5**
Charles City County, VA	RESAC / Woods Hole Model	520.0	10.3	**50.5**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	27.5	10.3	**2.7**	78.2	10.4	**7.5**
Chesterfield County, VA	RESAC / Woods Hole Model	101.6	24.0	**4.2**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	25.5	24.0	**1.1**	72.5	82.2	**0.9**
Fairfax County, VA	RESAC / Woods Hole Model	25.6	18.5	**1.4**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	19.2	18.5	**1.0**	50.7	42.0	**1.2**
Fauquier County, VA	RESAC / Woods Hole Model	117.4	13.2	**8.9**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	23.9	13.2	**1.8**	83.8	63.8	**1.3**
Frederick County, MD	RESAC / Woods Hole Model	43.0	30.0	**1.4**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	35.0	30.0	**1.2**	103.1	75.7	**1.4**
Hampton County, VA	RESAC / Woods Hole Model	8.7	9.5	**0.9**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	8.2	9.5	**0.9**	29.0	14.9	**1.9**
Hanover County, VA	RESAC / Woods Hole Model	109.5	36.4	**3.0**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	31.5	36.4	**0.9**	87.5	87.7	**1.0**
Henrico County, VA	RESAC / Woods Hole Model	71.6	20.4	**3.5**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	18.2	20.4	**0.9**	49.0	48.0	**1.0**
James City County, VA	RESAC / Woods Hole Model	73.5	38.3	**1.9**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	43.0	38.3	**1.1**	136.0	125.4	**1.1**
Loudoun County, VA	RESAC / Woods Hole Model	68.7	96.8	**0.7**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	105.4	96.8	**1.1**	577.1	331.4	**1.7**
Montgomery County, MD	RESAC / Woods Hole Model	27.5	14.5	**1.9**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	13.8	14.5	**1.0**	35.9	45.6	**0.8**
Newport News City, VA	RESAC / Woods Hole Model	13.7	5.1	**2.7**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	10.4	5.1	**2.0**	35.0	14.5	**2.4**
Northumberland County, VA	RESAC / Woods Hole Model	165.0	16.5	**10.0**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	16.1	16.5	**1.0**	41.5	29.9	**1.4**
Prince George's County, MD	RESAC / Woods Hole Model	22.5	10.9	**2.1**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	14.6	10.9	**1.3**	37.9	20.1	**1.9**
Prince William County, VA	RESAC / Woods Hole Model	50.4	30.6	**1.6**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	37.2	30.6	**1.2**	126.4	109.6	**1.2**
Richmond City, VA	RESAC / Woods Hole Model	18.6	-2.4	**-7.8**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	0.3	-2.4	**-0.1**	0.6	-5.0	**-0.1**
Stafford County, VA	RESAC / Woods Hole Model	81.8	48.5	**1.7**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	53.8	48.5	**1.1**	186.2	154.8	**1.2**
Westmoreland County, VA	RESAC / Woods Hole Model	49.7	8.0	**6.2**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	10.2	8.0	**1.3**	26.5	21.2	**1.3**
Williamsburg City, VA	RESAC / Woods Hole Model	18.5	3.4	**5.4**	-	-	**-**
	Phase 5.2 Model (WSSI Analysis)	3.1	3.4	**0.9**	21.5	19.4	**1.1**



Albemarle County

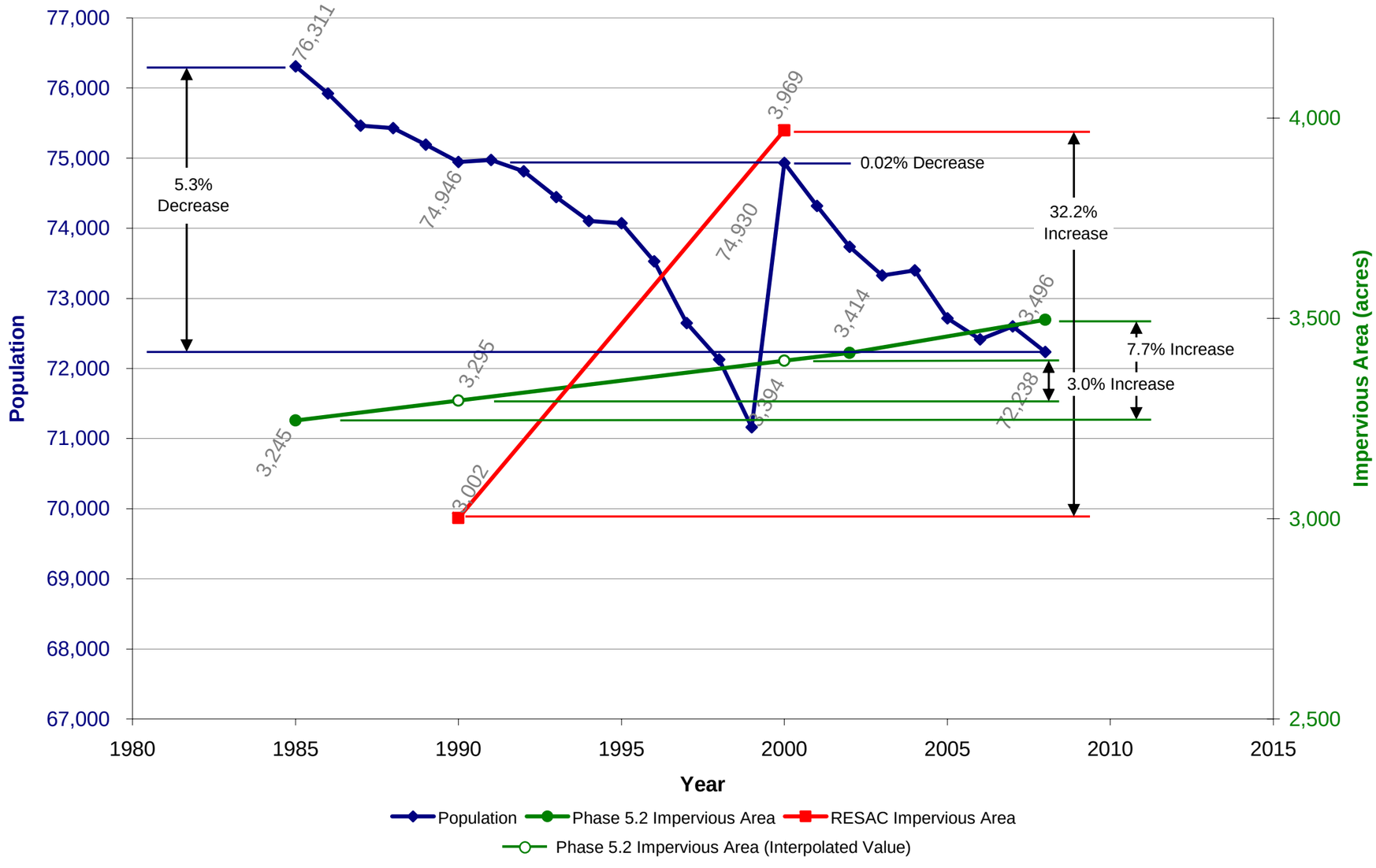
Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		1,145	61,229
1986		*1,189*	61,423
1987		*1,232*	63,004
1988		*1,276*	64,918
1989		*1,319*	66,538
1990	625	*1,363*	68,177
1991		*1,407*	69,240
1992		*1,450*	69,977
1993		*1,494*	71,340
1994		*1,537*	72,569
1995		*1,581*	75,744
1996		*1,624*	76,935
1997		*1,668*	77,615
1998		*1,711*	79,417
1999		*1,755*	80,145
2000	2264	*1,798*	79,236
2001		*1,842*	85,628
2002		1,885	86,320
2003			87,277
2004			88,650
2005			90,266
2006			91,870
2007			92,639
2008		2,172	94,075
% Change 1990-2000	262.0%	31.9%	16.2%



Alexandria City

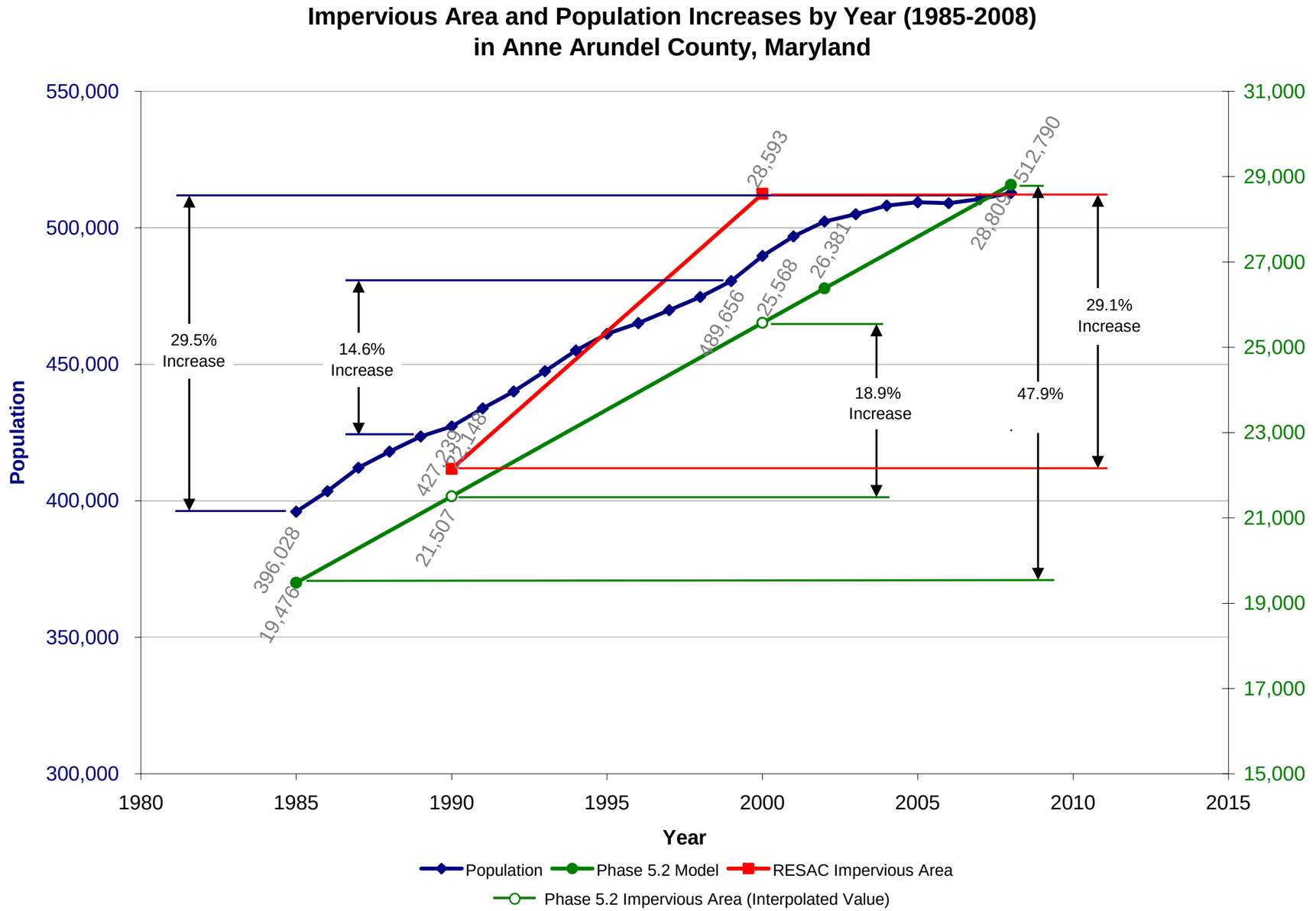
Year	RESAC / Woods	Phase 5.2 Model	Vector Data	Population
1985		3,817		111,324
1986		*3,859*		111,165
1987		*3,902*		110,611
1988		*3,944*		111,273
1989		*3,987*		111,198
1990	4,342	*4,029*		111,183
1991		*4,072*		112,523
1992		*4,114*		113,079
1993		*4,157*		113,821
1994		*4,199*		113,103
1995		*4,242*		113,418
1996		*4,284*		112,947
1997		*4,327*		113,688
1998		*4,370*		114,978
1999		*4,412*		117,390
2000	4,591	*4,455*		128,283
2001		*4,497*		133,090
2002		4,540		134,516
2003				135,162
2004				136,635
2005				137,602
2006				138,237
2007				139,848
2008		4,850	4,222	143,885
% Change 1990-2000	5.7%	10.5%	-	15.4%

Impervious Area and Population Increases by Year (1985-2008) in Allegany County, Maryland



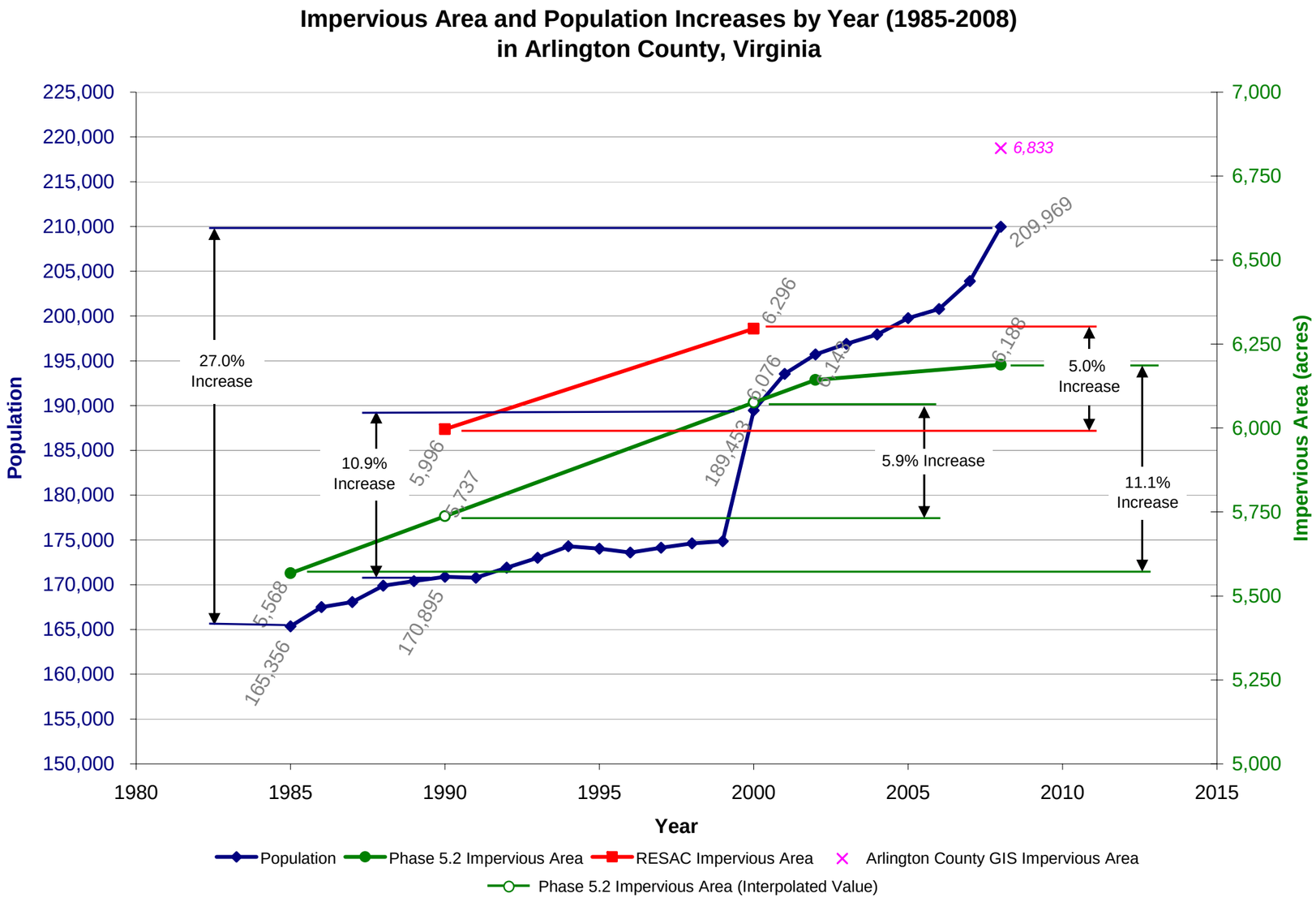
Allegany County

Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		3,245	76,311
1986		*3,255*	75,922
1987		*3,265*	75,466
1988		*3,275*	75,428
1989		*3,285*	75,193
1990	3,002	*3,295*	74,946
1991		*3,305*	74,974
1992		*3,315*	74,813
1993		*3,325*	74,445
1994		*3,335*	74,103
1995		*3,344*	74,073
1996		*3,354*	73,528
1997		*3,364*	72,649
1998		*3,374*	72,130
1999		*3,384*	71,162
2000	3,969	*3,394*	74,930
2001		*3,404*	74,320
2002		3,414	73,737
2003			73,327
2004			73,398
2005			72,716
2006			72,415
2007			72,603
2008		3,496	72,238
% Change 1990-2000	32.2%	3.0%	0.0%



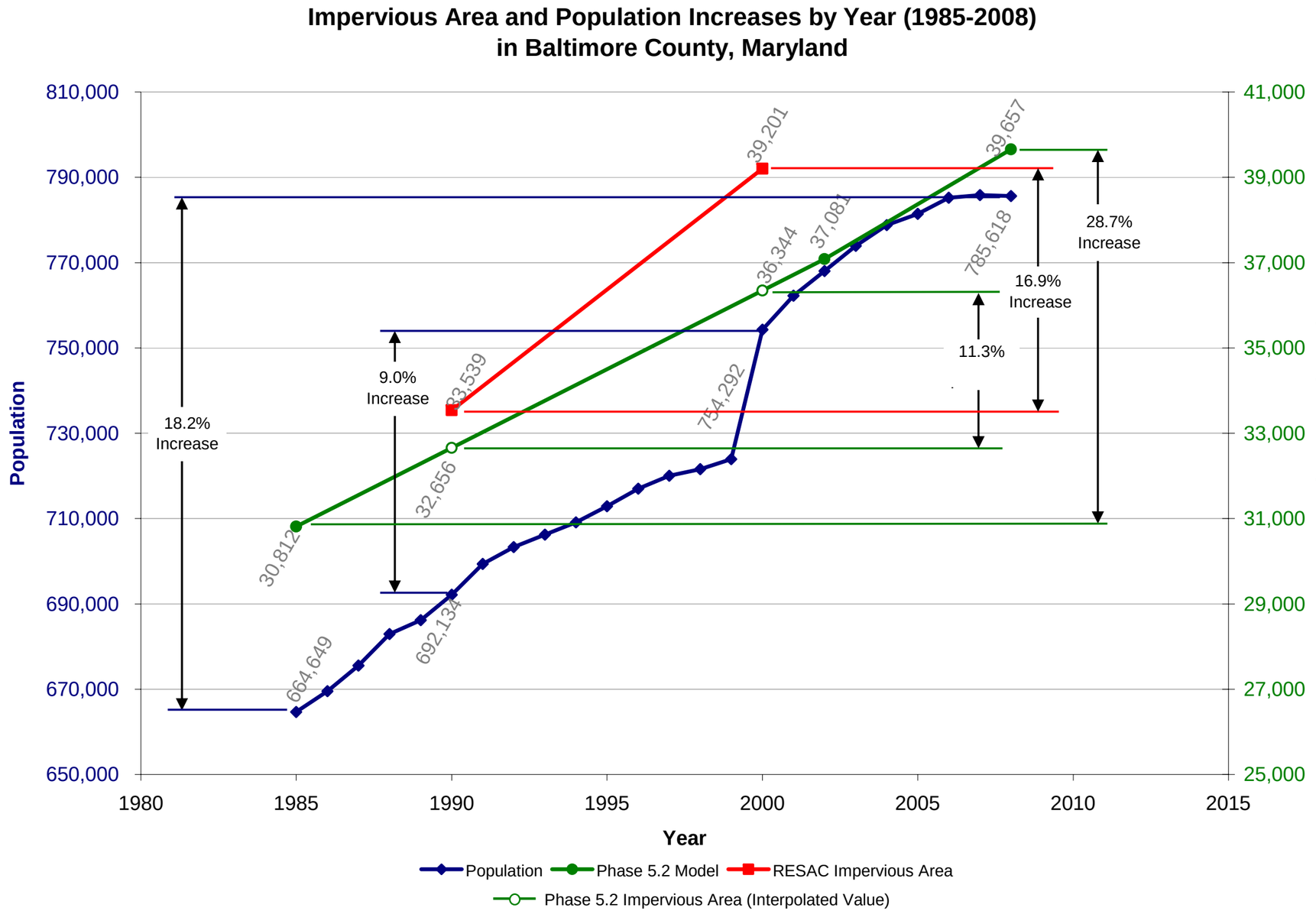
Anne Arundel County

Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		19,476	396,028
1986		*19,883*	403,532
1987		*20,289*	412,139
1988		*20,695*	418,047
1989		*21,101*	423,564
1990	22,148	*21,507*	427,239
1991		*21,913*	433,895
1992		*22,319*	440,020
1993		*22,725*	447,450
1994		*23,132*	455,038
1995		*23,538*	461,159
1996		*23,944*	465,087
1997		*24,350*	469,815
1998		*24,756*	474,682
1999		*25,162*	480,483
2000	28,593	*25,568*	489,656
2001		*25,975*	496,881
2002		26,381	502,267
2003			505,000
2004			508,132
2005			509,414
2006			509,037
2007			510,507
2008		28,809	512,790
% Change 1990-2000	29.1%	18.9%	14.6%



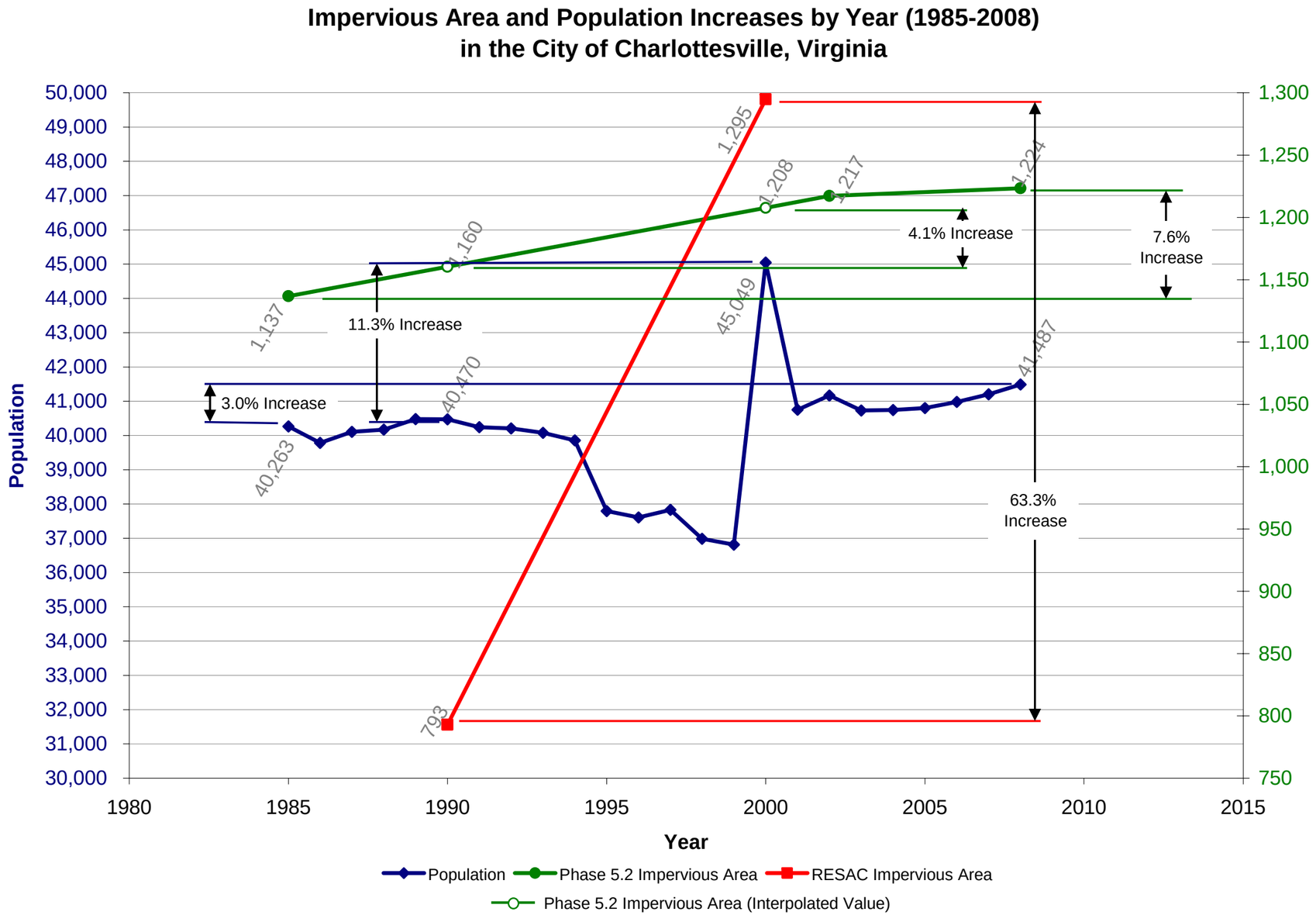
Arlington County

Year	RESAC / Woods Hole	Phase 5.2 Model	Vector Data	Population
1985		5,568		165,356
1986		*5,602*		167,502
1987		*5,635*		168,060
1988		*5,669*		169,903
1989		*5,703*		170,391
1990	5,996	*5,737*		170,895
1991		*5,771*		170,774
1992		*5,805*		171,911
1993		*5,839*		173,009
1994		*5,872*		174,298
1995		*5,906*		174,038
1996		*5,940*		173,591
1997		*5,974*		174,130
1998		*6,008*		174,607
1999		*6,042*		174,848
2000	6,296	*6,076*		189,453
2001		*6,110*		193,550
2002		6,143		195,724
2003				196,890
2004				197,955
2005				199,761
2006				200,789
2007				203,909
2008		6,188	6,833	209,969
% Change 1990-2000	5.0%	5.9%	-	10.9%



Baltimore County

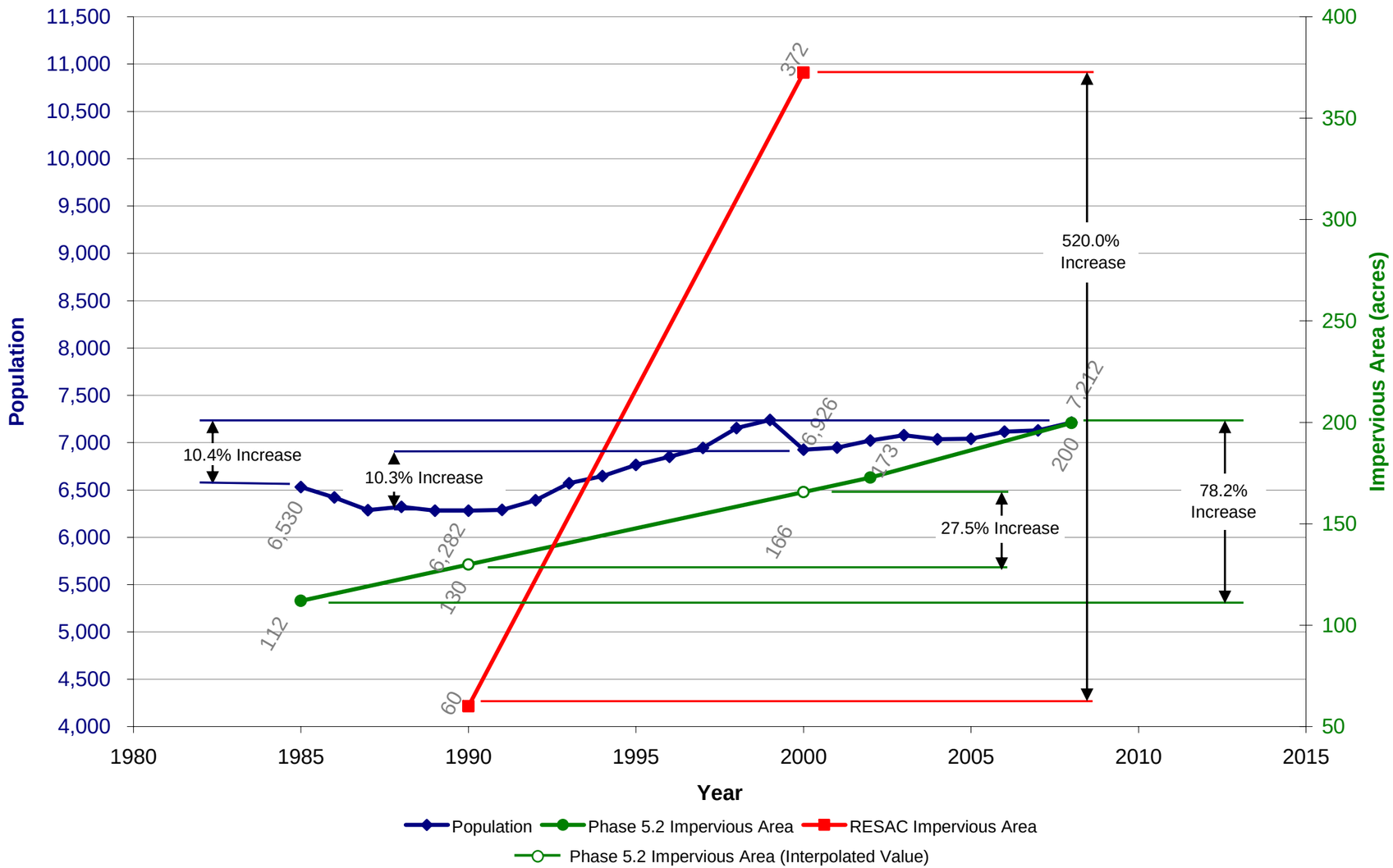
Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		30,812	664,649
1986		*31,181*	669,544
1987		*31,550*	675,514
1988		*31,919*	682,941
1989		*32,287*	686,188
1990	33,539	*32,656*	692,134
1991		*33,025*	699,337
1992		*33,394*	703,337
1993		*33,762*	706,225
1994		*34,131*	709,104
1995		*34,500*	712,904
1996		*34,869*	716,974
1997		*35,237*	720,043
1998		*35,606*	721,556
1999		*35,975*	723,914
2000	39,201	*36,344*	754,292
2001		*36,712*	762,269
2002		37,081	768,047
2003			773,921
2004			778,810
2005			781,452
2006			785,200
2007			785,830
2008		39,657	785,618
% Change 1990-2000	16.9%	11.3%	9.0%



Charlottesville City

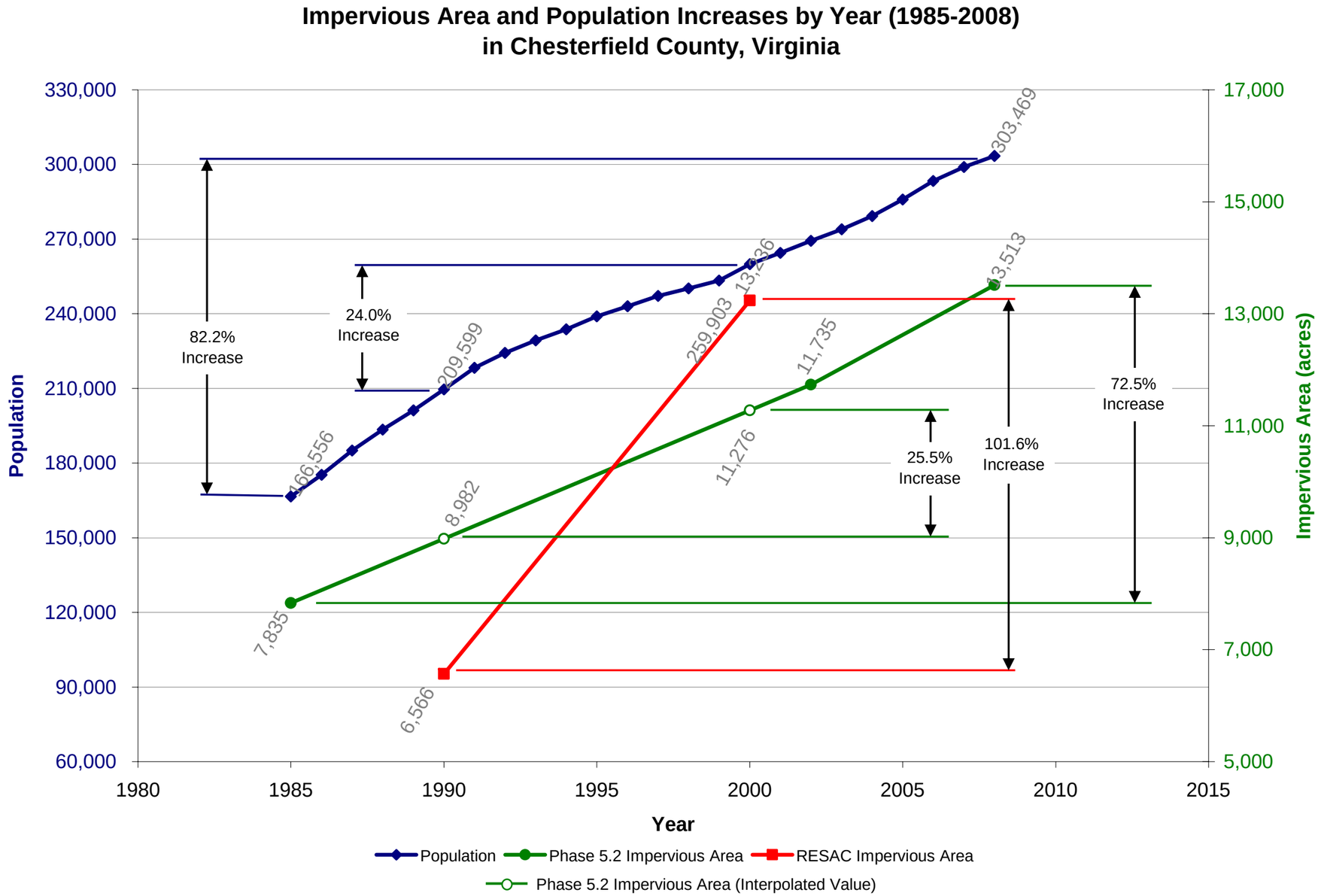
Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		1137	40263
1986		*1142*	39784
1987		*1146*	40107
1988		*1151*	40173
1989		*1156*	40482
1990	793	*1160*	40470
1991		*1165*	40246
1992		*1170*	40208
1993		*1175*	40079
1994		*1179*	39856
1995		*1184*	37794
1996		*1189*	37609
1997		*1194*	37830
1998		*1198*	36988
1999		*1203*	36815
2000	1295	*1208*	45049
2001		*1212*	40750
2002		1217	41169
2003			40730
2004			40745
2005			40805
2006			40982
2007			41206
2008		1224	41487
% Change 1990-2000	63.3%	4.1%	11.3%

Impervious Area and Population Increases by Year (1985-2008) in Charles City County, Virginia



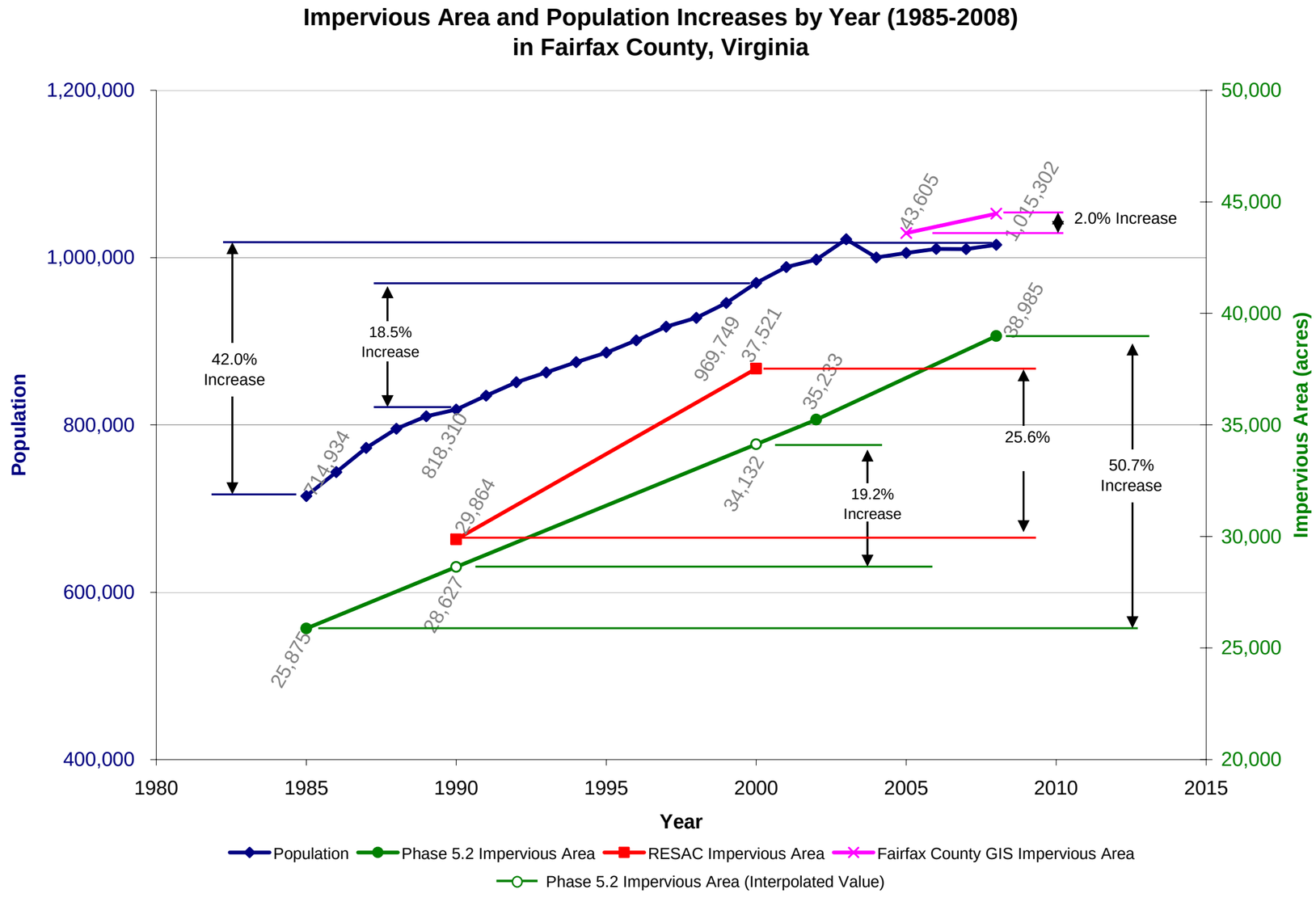
Charles City County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		112	6,530
1986		*116*	6,422
1987		*119*	6,287
1988		*123*	6,321
1989		*126*	6,282
1990	60	*130*	6,282
1991		*133*	6,290
1992		*137*	6,393
1993		*141*	6,572
1994		*144*	6,646
1995		*148*	6,764
1996		*151*	6,852
1997		*155*	6,946
1998		*158*	7,153
1999		*162*	7,240
2000	372	*166*	6,926
2001		*169*	6,947
2002		173	7,023
2003			7,079
2004			7,037
2005			7,041
2006			7,116
2007			7,130
2008		200	7,212
% Change 1990-2000	520.0%	27.5%	10.3%



Chesterfield County

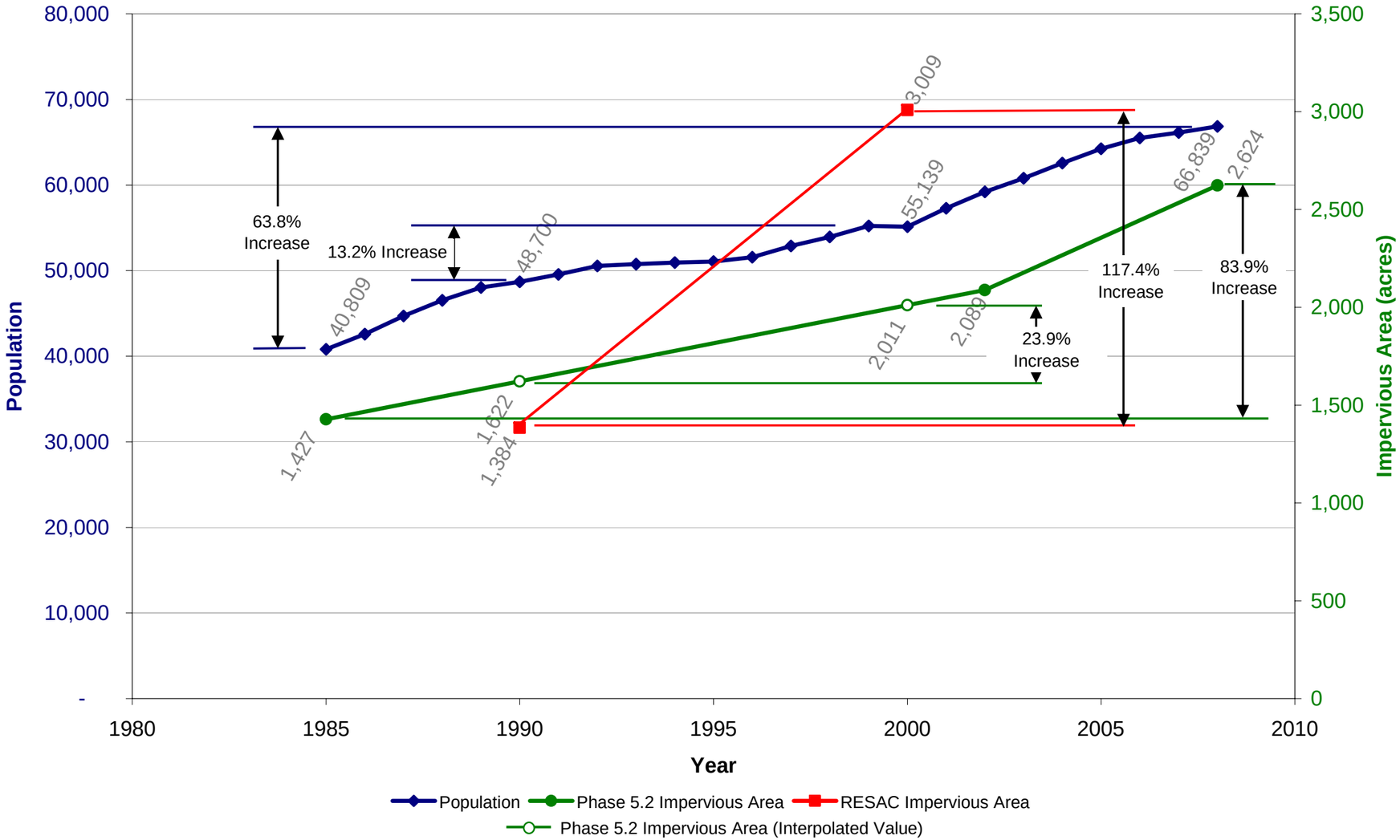
Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		7,835	166,556
1986		*8,064*	175,256
1987		*8,294*	185,053
1988		*8,523*	193,417
1989		*8,753*	201,200
1990	6,566	*8,982*	209,599
1991		*9,211*	218,316
1992		*9,441*	224,307
1993		*9,670*	229,287
1994		*9,900*	233,721
1995		*10,129*	238,932
1996		*10,359*	243,030
1997		*10,588*	247,155
1998		*10,817*	250,161
1999		*11,047*	253,365
2000	13,236	*11,276*	259,903
2001		*11,506*	264,469
2002		11,735	269,266
2003			273,909
2004			279,243
2005			285,891
2006			293,361
2007			299,022
2008		13,513	303,469
% Change 1990-2000	101.6%	25.5%	24.0%



Fairfax County

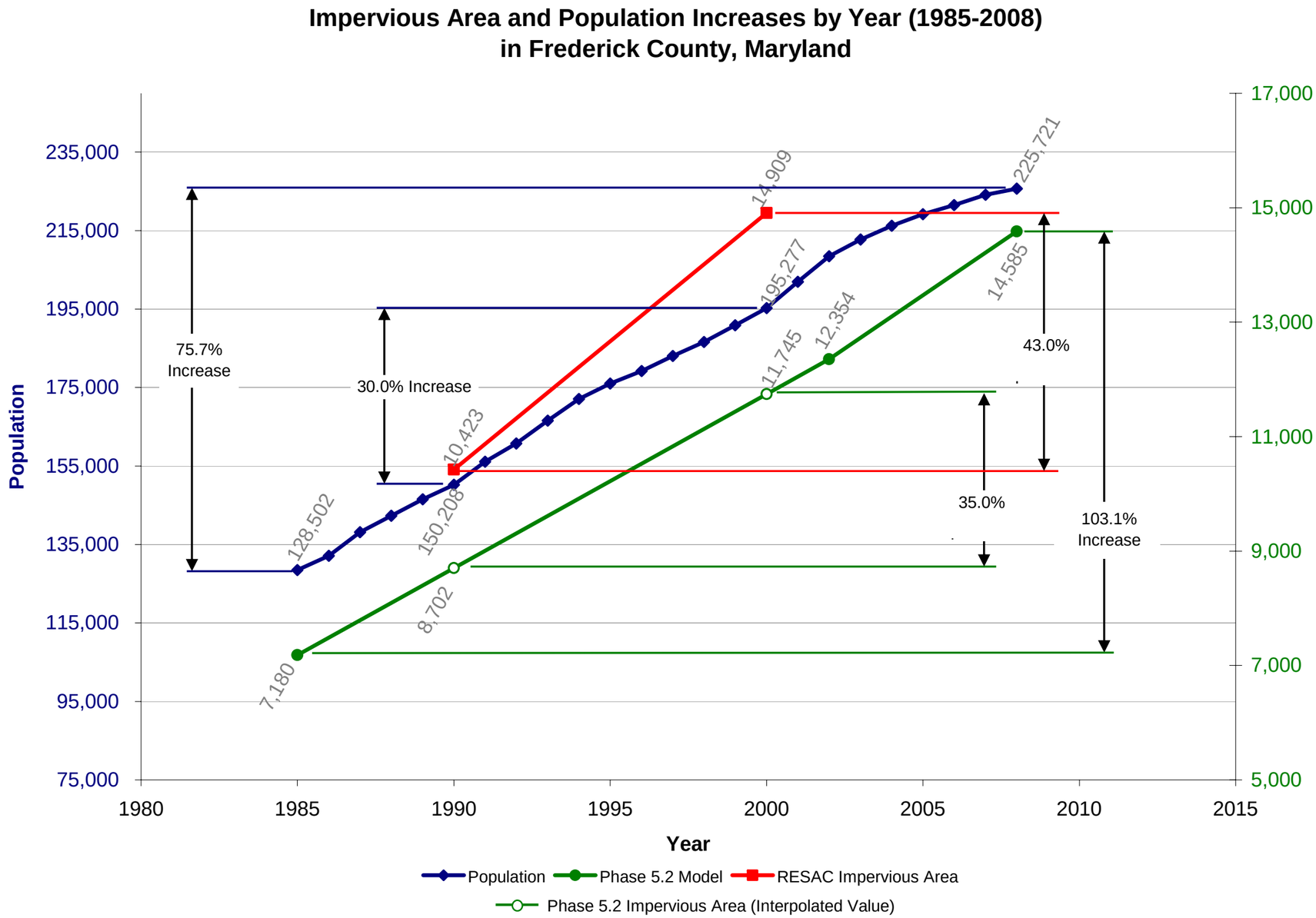
Year	RESAC / Woods Hole	Phase 5.2 Model	Vector Data	Population
1985		25,875		714,934
1986		*26,426*		743,504
1987		*26,976*		772,555
1988		*27,527*		795,374
1989		*28,077*		810,406
1990	29,864	*28,627*		818,310
1991		*29,178*		835,010
1992		*29,728*		851,021
1993		*30,279*		862,658
1994		*30,829*		875,059
1995		*31,380*		886,379
1996		*31,930*		901,092
1997		*32,481*		917,488
1998		*33,031*		927,895
1999		*33,581*		945,717
2000	37,521	*34,132*		969,749
2001		*34,682*		988,714
2002		35,233		997,580
2003				1,021,838
2004				1,000,046
2005			43,605	1,005,616
2006				1,010,443
2007				1,010,241
2008		38,985	44,474	1,015,302
% Change 1990-2000	25.6%	19.2%	-	18.5%

Impervious Area and Population Increases by Year (1985-2008) in Fauquier County, Virginia



Fauquier County

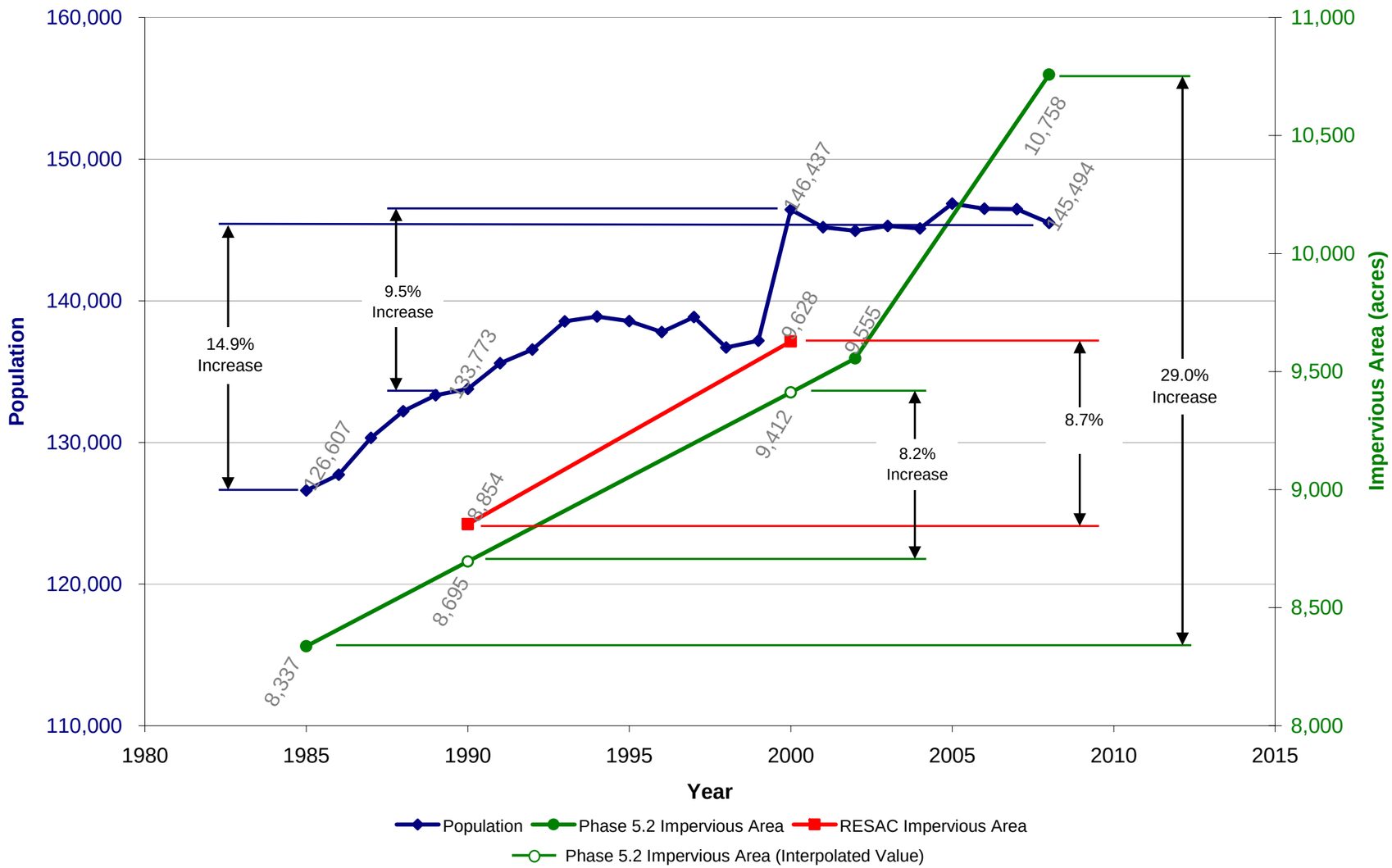
Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		1,427	40,809
1986		*1,466*	42,576
1987		*1,505*	44,716
1988		*1,544*	46,545
1989		*1,583*	48,044
1990	1,384	*1,622*	48,700
1991		*1,661*	49,563
1992		*1,699*	50,547
1993		*1,738*	50,742
1994		*1,777*	50,927
1995		*1,816*	51,057
1996		*1,855*	51,573
1997		*1,894*	52,881
1998		*1,933*	53,939
1999		*1,972*	55,206
2000	3,009	*2,011*	55,139
2001		*2,050*	57,280
2002		2,089	59,195
2003			60,797
2004			62,561
2005			64,225
2006			65,512
2007			66,122
2008		2,624	66,839
% Change 1990-2000	117.5%	24.0%	13.2%



Frederick County

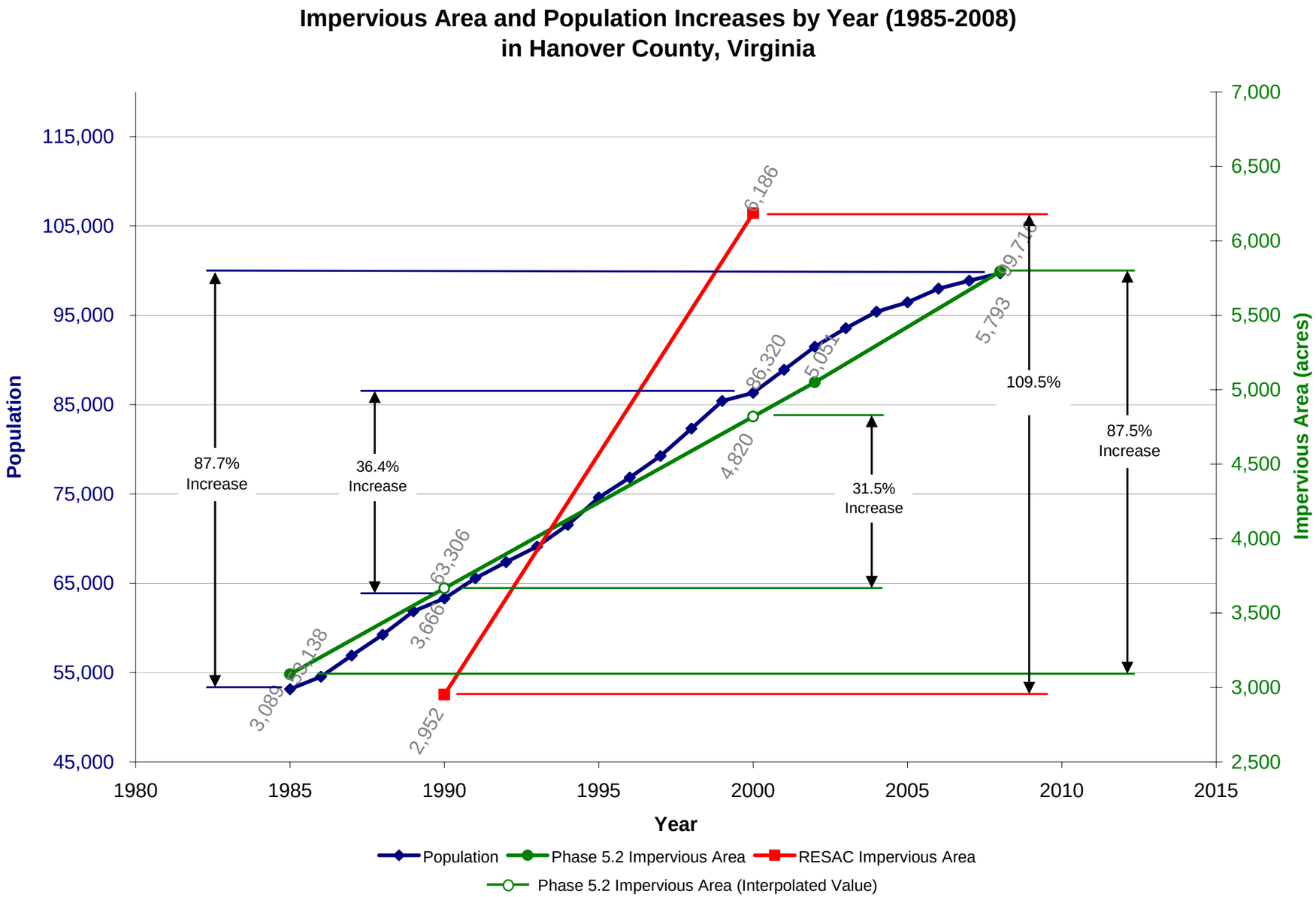
Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		7,180	128,502
1986		*7,484*	132,124
1987		*7,789*	138,113
1988		*8,093*	142,328
1989		*8,397*	146,517
1990	10,423	*8,702*	150,208
1991		*9,006*	156,133
1992		*9,310*	160,723
1993		*9,615*	166,572
1994		*9,919*	172,082
1995		*10,223*	176,044
1996		*10,528*	179,223
1997		*10,832*	183,042
1998		*11,136*	186,621
1999		*11,441*	190,869
2000	14,909	*11,745*	195,277
2001		*12,049*	201,942
2002		12,354	208,498
2003			212,735
2004			216,232
2005			219,178
2006			221,492
2007			224,147
2008		14,585	225,721
% Change 1990-2000	43.0%	35.0%	30.0%

Impervious Area and Population Increases by Year (1985-2008) in the City of Hampton, Virginia



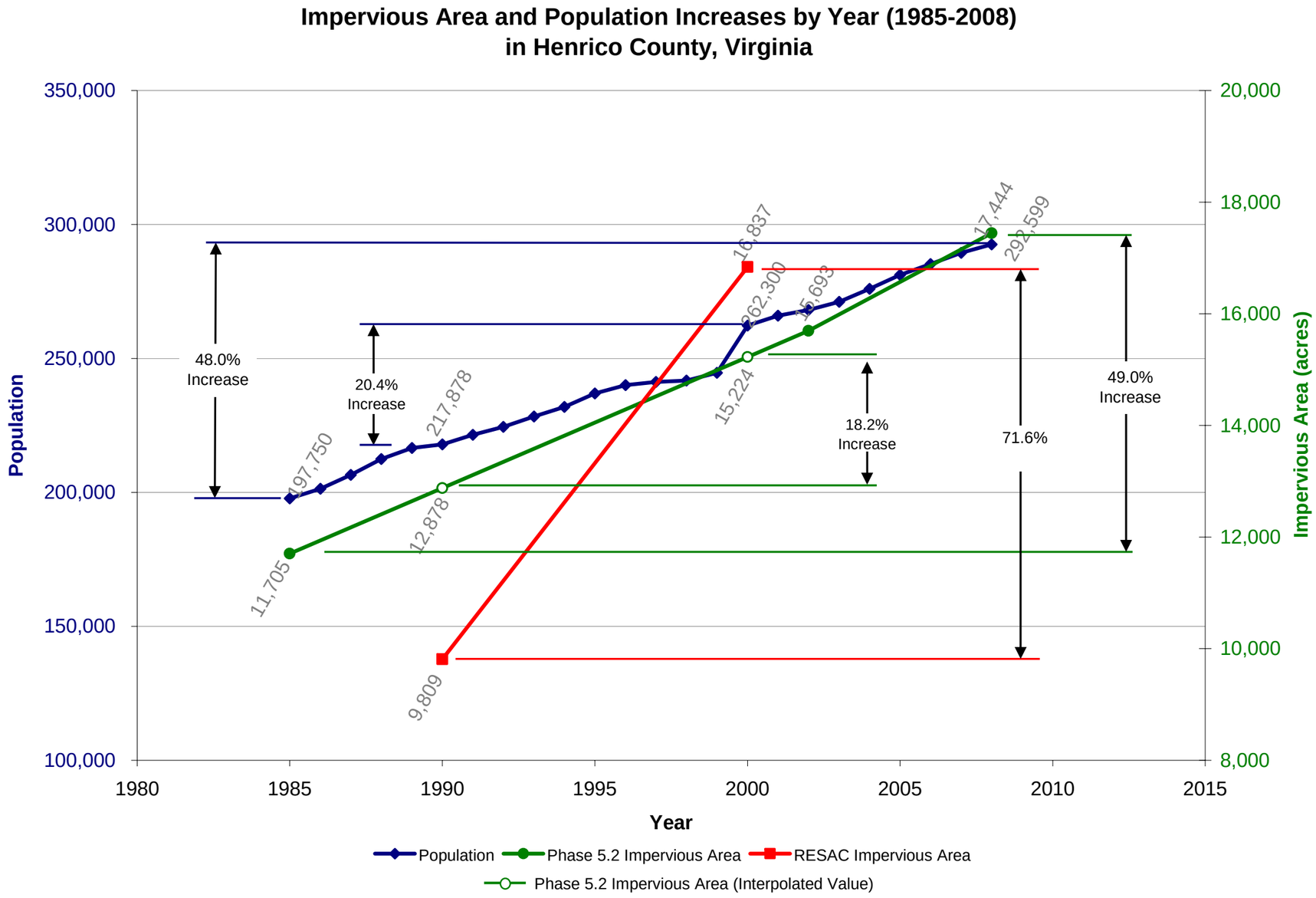
Hampton City

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		8,337	126,607
1986		*8,408*	127,730
1987		*8,480*	130,319
1988		*8,552*	132,200
1989		*8,624*	133,327
1990	8,854	*8,695*	133,773
1991		*8,767*	135,589
1992		*8,839*	136,561
1993		*8,910*	138,545
1994		*8,982*	138,885
1995		*9,054*	138,575
1996		*9,125*	137,795
1997		*9,197*	138,846
1998		*9,269*	136,706
1999		*9,340*	137,193
2000	9,628	*9,412*	146,437
2001		*9,484*	145,196
2002		9,555	144,939
2003			145,288
2004			145,105
2005			146,859
2006			146,503
2007			146,466
2008		10,758	145,494
% Change 1990-2000	8.7%	8.2%	9.5%



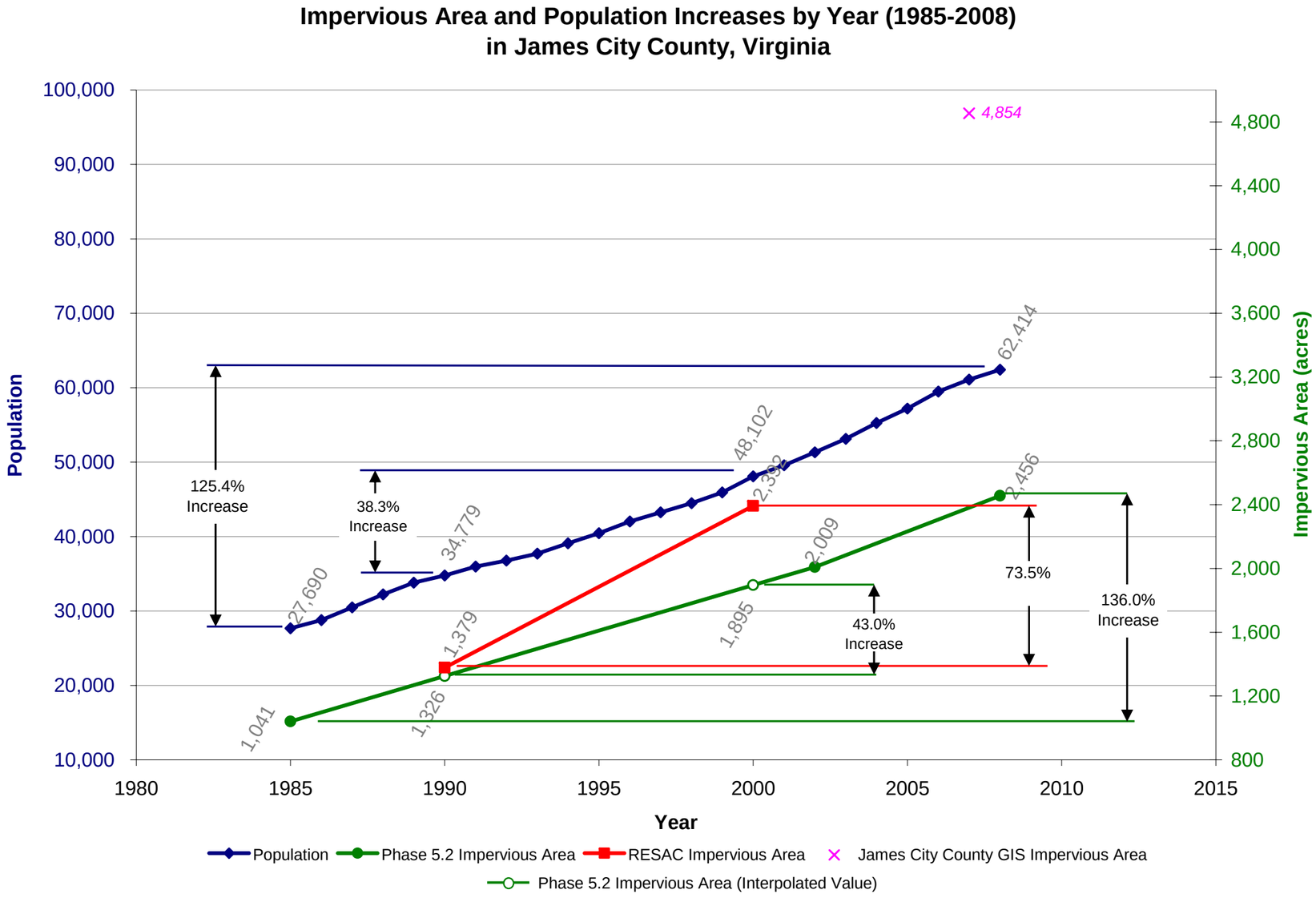
Hanover County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		3,089	53,138
1986		*3,205*	54,551
1987		*3,320*	56,897
1988		*3,436*	59,254
1989		*3,551*	61,864
1990	2,952	*3,666*	63,306
1991		*3,782*	65,558
1992		*3,897*	67,360
1993		*4,012*	69,108
1994		*4,128*	71,539
1995		*4,243*	74,586
1996		*4,359*	76,823
1997		*4,474*	79,253
1998		*4,589*	82,302
1999		*4,705*	85,410
2000	6,186	*4,820*	86,320
2001		*4,935*	88,895
2002		5,051	91,485
2003			93,548
2004			95,414
2005			96,458
2006			97,992
2007			98,862
2008		5,793	99,716
% Change 1990-2000	109.5%	31.5%	36.4%



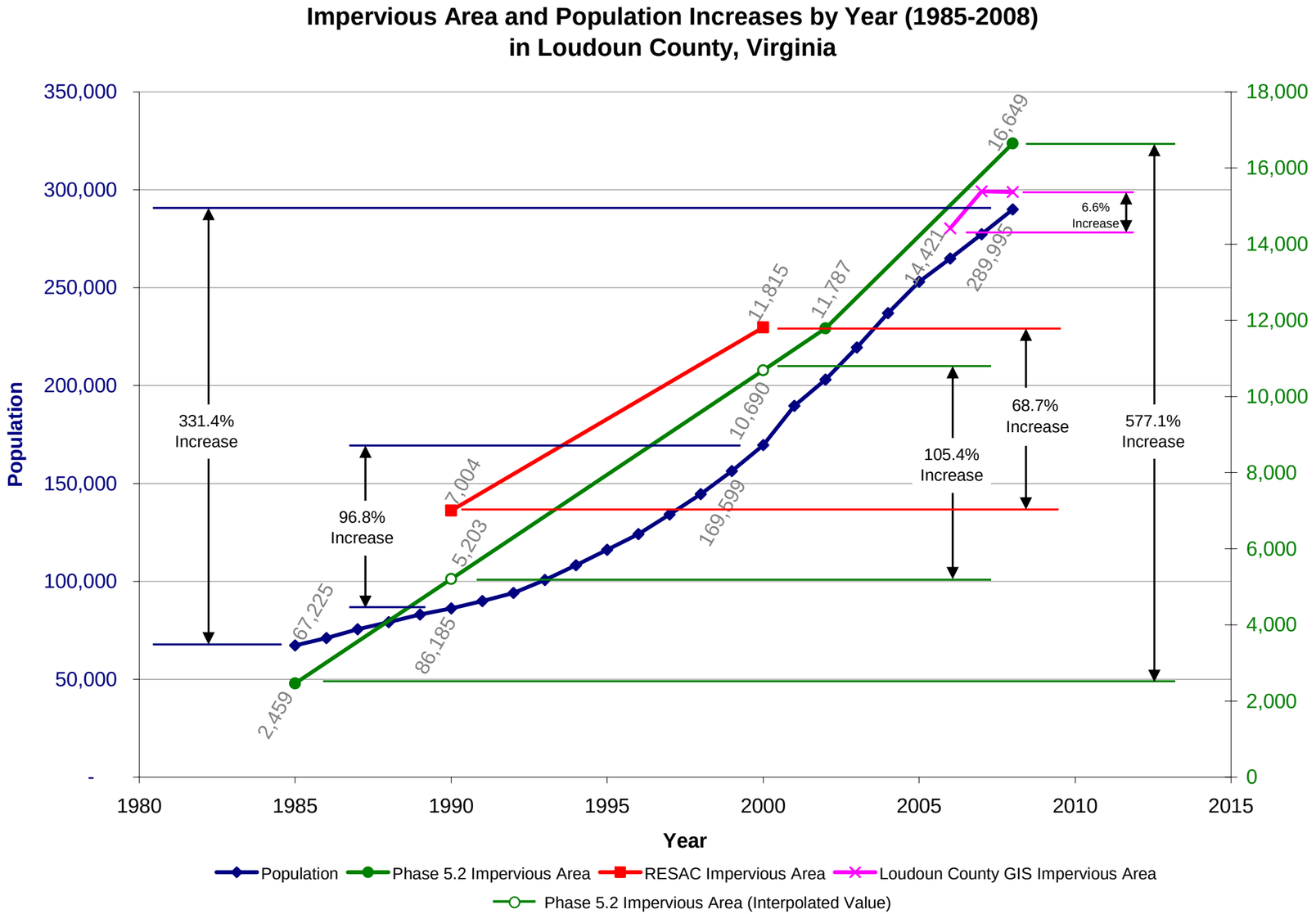
Henrico County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		11,705	197,750
1986		*11,940*	201,376
1987		*12,174*	206,524
1988		*12,409*	212,486
1989		*12,644*	216,547
1990	9,809	*12,878*	217,878
1991		*13,113*	221,520
1992		*13,347*	224,425
1993		*13,582*	228,353
1994		*13,816*	231,942
1995		*14,051*	236,936
1996		*14,286*	240,056
1997		*14,520*	241,245
1998		*14,755*	241,766
1999		*14,989*	244,652
2000	16,837	*15,224*	262,300
2001		*15,458*	265,957
2002		15,693	268,099
2003			271,104
2004			275,996
2005			281,169
2006			285,187
2007			289,460
2008		17,444	292,599
% Change 1990-2000	71.6%	18.2%	20.4%



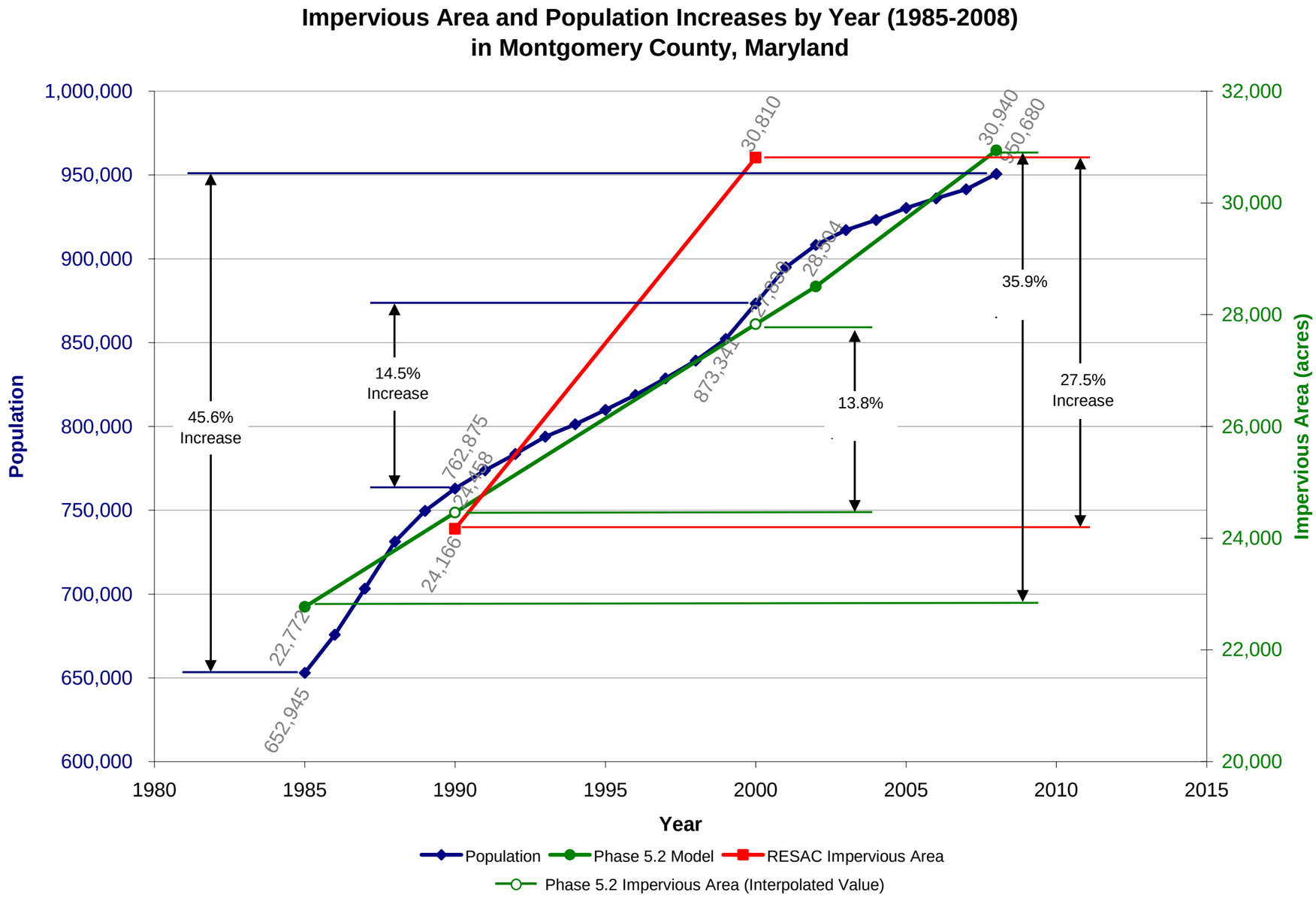
James City County

Year	RESAC / Woods Hole	Phase 5.2 Model	Vector Data	Popu-lation
1985		1,041		27,690
1986		*1,098*		28,774
1987		*1,155*		30,485
1988		*1,212*		32,212
1989		*1,269*		33,811
1990	1,379	*1,326*		34,779
1991		*1,383*		35,966
1992		*1,440*		36,764
1993		*1,496*		37,716
1994		*1,553*		39,088
1995		*1,610*		40,439
1996		*1,667*		42,040
1997		*1,724*		43,254
1998		*1,781*		44,488
1999		*1,838*		45,945
2000	2,392	*1,895*		48,102
2001		*1,952*		49,570
2002		2,009		51,313
2003				53,113
2004				55,246
2005				57,187
2006				59,484
2007			4,854	61,094
2008		2,456		62,414
% Change 1990-2000	73.5%	43.0%	-	38.3%



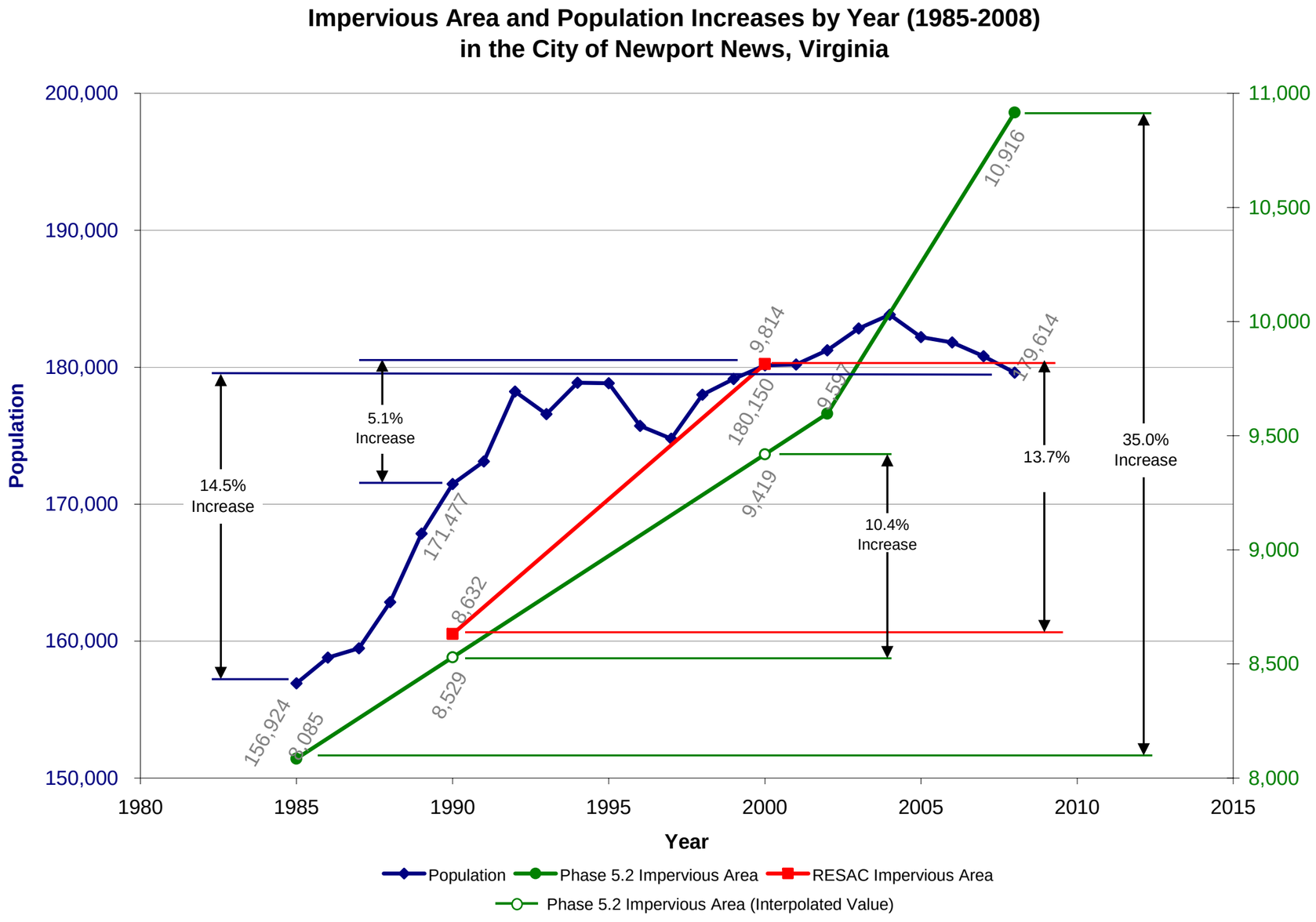
Loudoun County

Year	RESAC / Woods Hole	Phase 5.2 Model	Vector Data	Population
1985		2,459		67,225
1986		*3,008*		71,026
1987		*3,557*		75,578
1988		*4,106*		79,117
1989		*4,654*		83,084
1990	7,004	*5,203*		86,185
1991		*5,752*		89,971
1992		*6,300*		94,047
1993		*6,849*		100,723
1994		*7,398*		108,187
1995		*7,946*		116,140
1996		*8,495*		124,114
1997		*9,044*		134,170
1998		*9,592*		144,514
1999		*10,141*		156,284
2000	11,815	*10,690*		169,599
2001		*11,239*		189,649
2002		11,787		203,007
2003				219,423
2004				236,965
2005				253,053
2006			14,421	264,958
2007			15,389	277,346
2008		16,649	15,371	289,995
% Change 1990-2000	68.7%	105.5%	-	96.8%



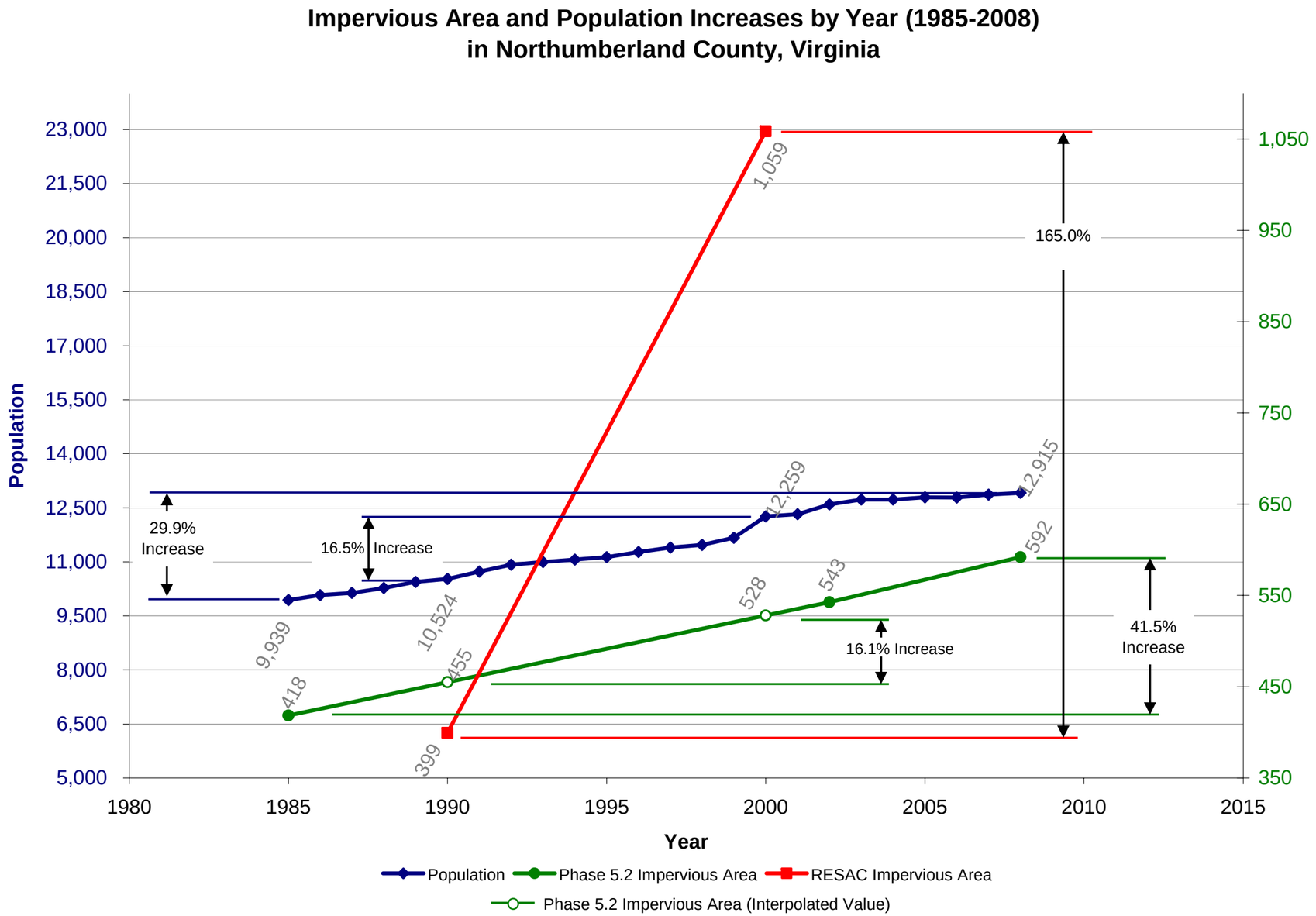
Montgomery County

Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		22,772	652,945
1986		*23,109*	675,784
1987		*23,446*	703,273
1988		*23,783*	731,351
1989		*24,120*	749,638
1990	24,166	*24,458*	762,875
1991		*24,795*	773,755
1992		*25,132*	783,567
1993		*25,469*	793,903
1994		*25,806*	801,356
1995		*26,144*	809,814
1996		*26,481*	818,753
1997		*26,818*	828,617
1998		*27,155*	839,158
1999		*27,492*	852,174
2000	30,810	*27,830*	873,341
2001		*28,167*	894,878
2002		28,504	908,233
2003			917,160
2004			923,094
2005			930,286
2006			936,070
2007			941,491
2008		30,940	950,680
% Change 1990-2000	27.5%	13.8%	14.5%



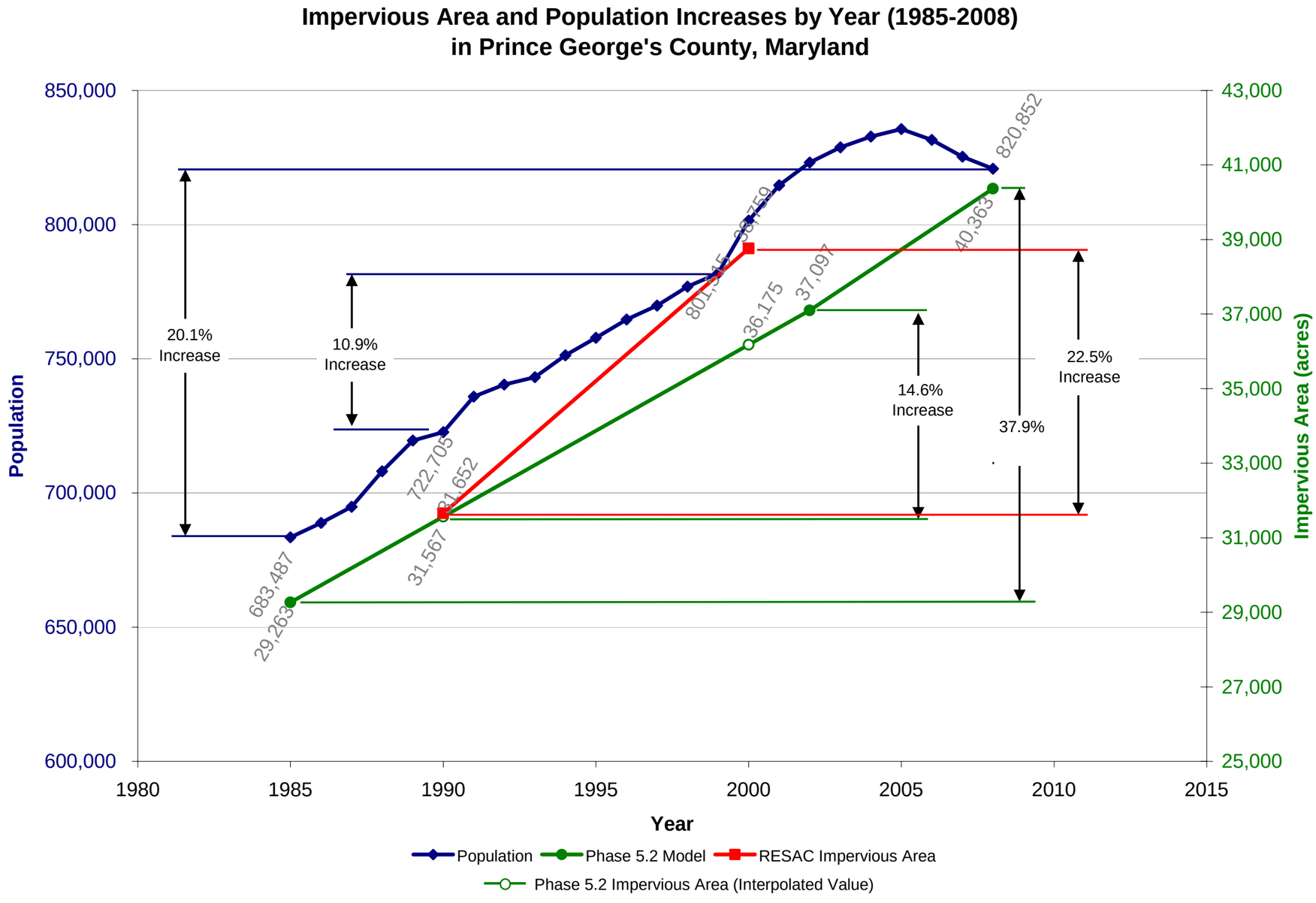
Newport News City

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		8,085	156,924
1986		*8,174*	158,808
1987		*8,263*	159,484
1988		*8,352*	162,854
1989		*8,441*	167,851
1990	8,632	*8,529*	171,477
1991		*8,618*	173,113
1992		*8,707*	178,233
1993		*8,796*	176,580
1994		*8,885*	178,874
1995		*8,974*	178,837
1996		*9,063*	175,720
1997		*9,152*	174,792
1998		*9,241*	178,001
1999		*9,330*	179,138
2000	9,814	*9,419*	180,150
2001		*9,508*	180,192
2002		9,597	181,230
2003			182,826
2004			183,832
2005			182,213
2006			181,812
2007			180,810
2008		10,916	179,614
% Change 1990-2000	13.7%	10.4%	5.1%



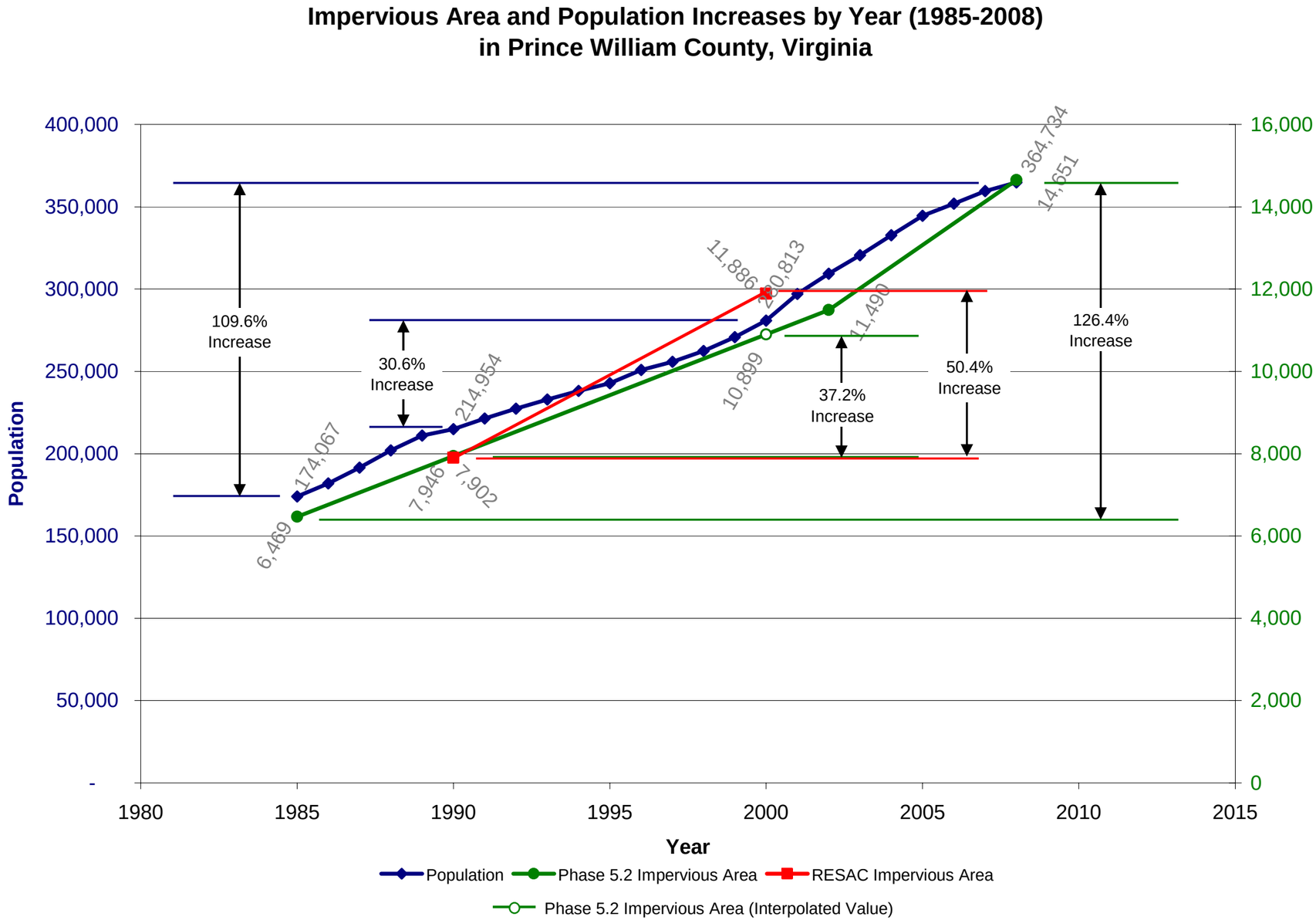
Northumberland County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		418	9,939
1986		*426*	10,079
1987		*433*	10,136
1988		*440*	10,275
1989		*448*	10,447
1990	399	*455*	10,524
1991		*462*	10,728
1992		*470*	10,920
1993		*477*	10,993
1994		*484*	11,061
1995		*492*	11,134
1996		*499*	11,271
1997		*506*	11,396
1998		*513*	11,473
1999		*521*	11,668
2000	1,059	*528*	12,259
2001		*535*	12,325
2002		543	12,592
2003			12,733
2004			12,732
2005			12,795
2006			12,788
2007			12,867
2008		592	12,915
% Change 1990-2000	165.0%	16.1%	16.5%



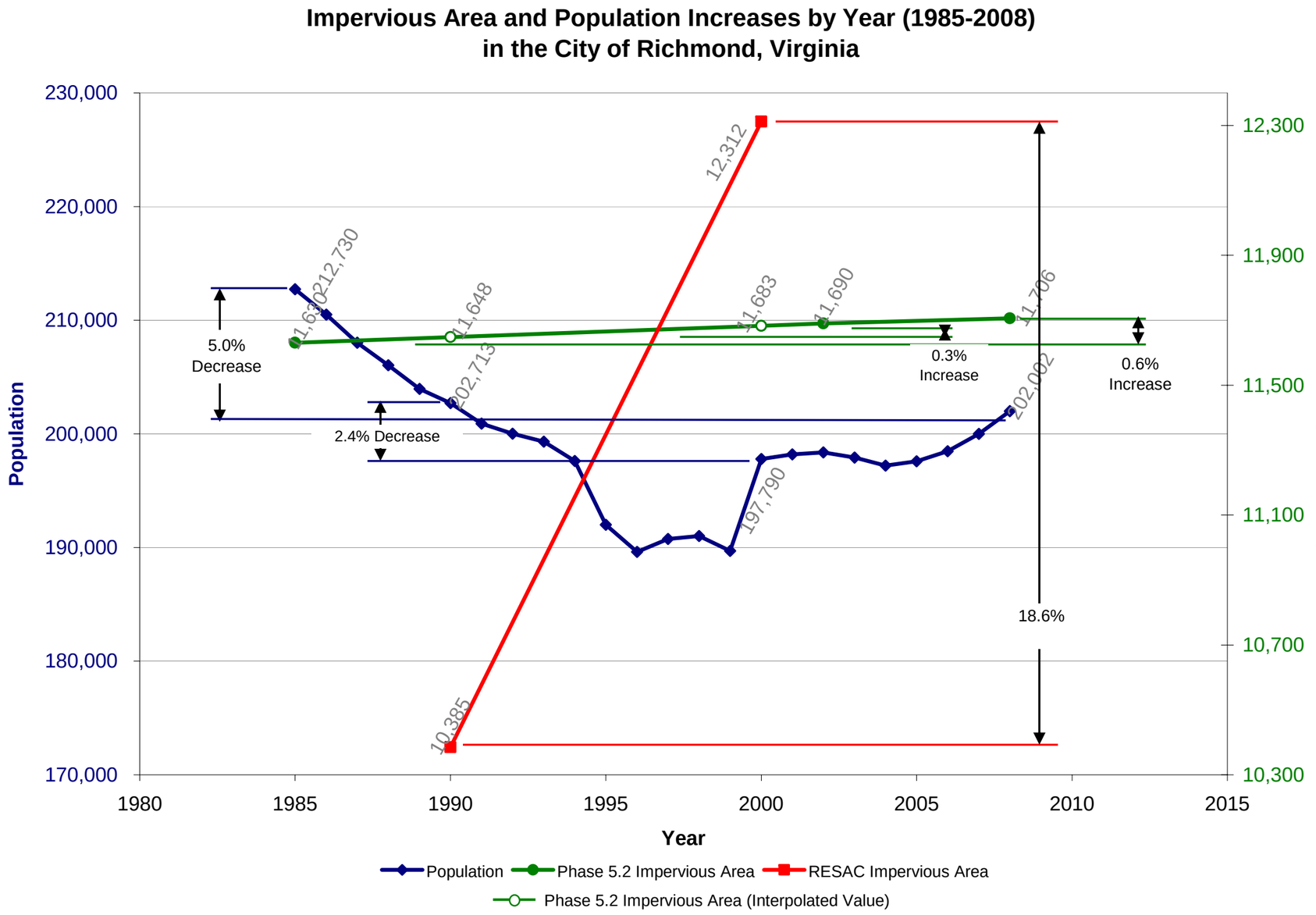
Prince George's County

Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		29,263	683,487
1986		*29,723*	688,863
1987		*30,184*	694,845
1988		*30,645*	708,095
1989		*31,106*	719,550
1990	31,652	*31,567*	722,705
1991		*32,028*	735,915
1992		*32,488*	740,390
1993		*32,949*	743,156
1994		*33,410*	751,282
1995		*33,871*	757,795
1996		*34,332*	764,644
1997		*34,792*	769,840
1998		*35,253*	776,907
1999		*35,714*	781,781
2000	38,759	*36,175*	801,515
2001		*36,636*	814,689
2002		37,097	823,186
2003			828,822
2004			832,806
2005			835,588
2006			831,602
2007			825,318
2008		40,363	820,852
% Change 1990-2000	22.5%	14.6%	10.9%



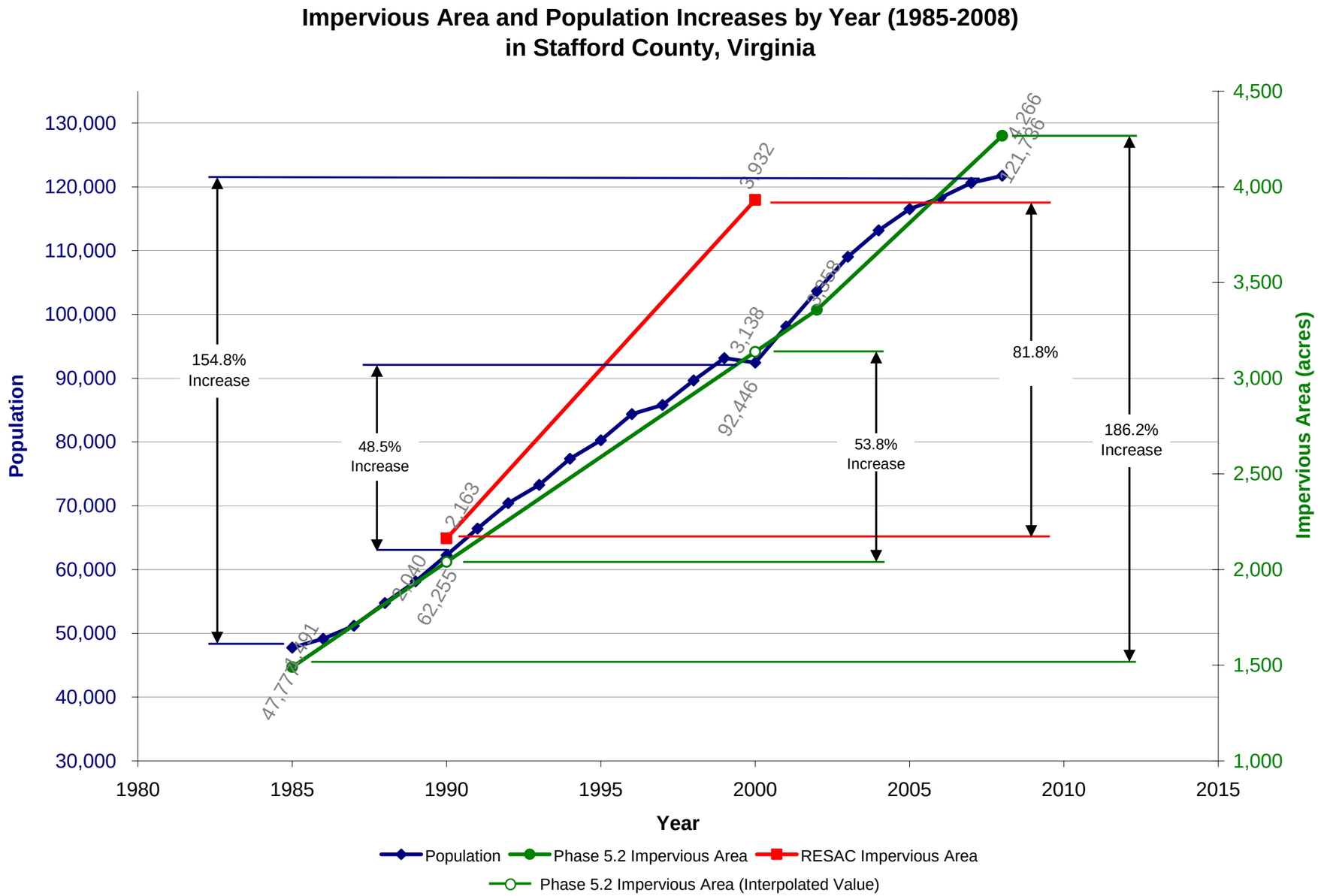
Prince William County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		6,469	174,067
1986		*6,764*	181,935
1987		*7,060*	191,570
1988		*7,355*	202,079
1989		*7,650*	211,064
1990	7,902	*7,946*	214,954
1991		*8,241*	221,284
1992		*8,537*	227,384
1993		*8,832*	232,900
1994		*9,127*	238,215
1995		*9,423*	242,718
1996		*9,718*	250,892
1997		*10,013*	255,786
1998		*10,309*	262,414
1999		*10,604*	270,841
2000	11,886	*10,899*	280,813
2001		*11,195*	297,080
2002		11,490	309,312
2003			320,618
2004			332,689
2005			344,572
2006			351,835
2007			359,588
2008		14,651	364,734
% Change 1990-2000	50.4%	37.2%	30.6%



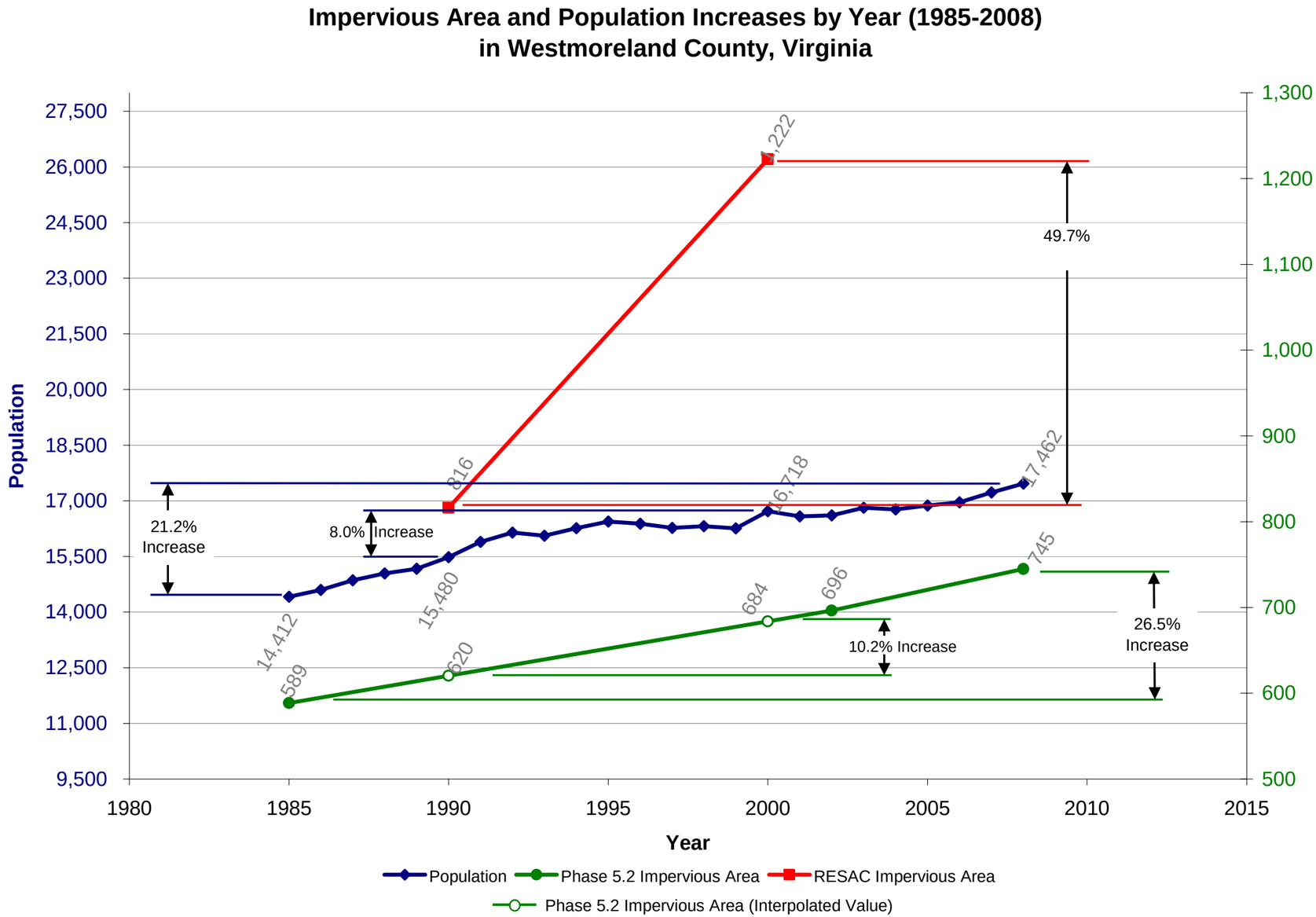
City of Richmond

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		11,630	212,730
1986		*11,634*	210,497
1987		*11,637*	208,018
1988		*11,641*	206,050
1989		*11,644*	203,963
1990	10,385	*11,648*	202,713
1991		*11,651*	200,900
1992		*11,655*	200,024
1993		*11,658*	199,303
1994		*11,662*	197,610
1995		*11,665*	192,003
1996		*11,669*	189,608
1997		*11,672*	190,757
1998		*11,676*	191,001
1999		*11,679*	189,700
2000	12,312	*11,683*	197,790
2001		*11,686*	198,204
2002		11,690	198,356
2003			197,924
2004			197,194
2005			197,586
2006			198,480
2007			199,991
2008		11,706	202,002
% Change 1990-2000	18.6%	0.3%	-2.4%



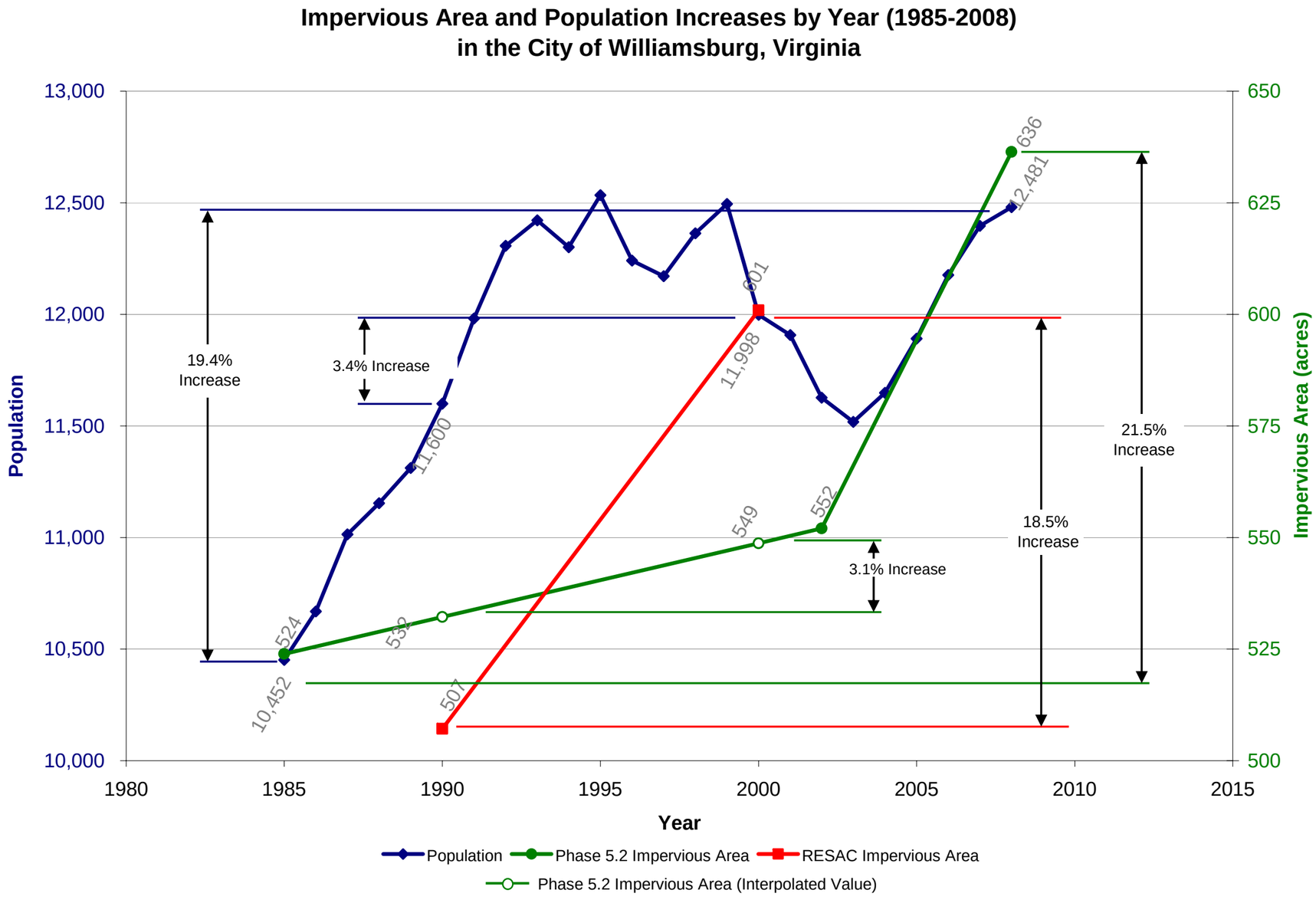
Stafford County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		1,491	47,777
1986		*1,600*	49,143
1987		*1,710*	51,193
1988		*1,820*	54,749
1989		*1,930*	58,139
1990	2,163	*2,040*	62,255
1991		*2,150*	66,444
1992		*2,259*	70,409
1993		*2,369*	73,261
1994		*2,479*	77,379
1995		*2,589*	80,275
1996		*2,699*	84,382
1997		*2,809*	85,799
1998		*2,918*	89,668
1999		*3,028*	93,160
2000	3,932	*3,138*	92,446
2001		*3,248*	98,101
2002		3,358	103,645
2003			109,035
2004			113,164
2005			116,536
2006			118,299
2007			120,621
2008		4,266	121,736
% Change 1990-2000	81.8%	53.8%	48.5%



Westmoreland County

Year	RESAC / Woods Hole	Phase 5.2 Model	Population
1985		589	14,412
1986		*595*	14,596
1987		*601*	14,861
1988		*608*	15,044
1989		*614*	15,169
1990	816	*620*	15,480
1991		*627*	15,889
1992		*633*	16,143
1993		*639*	16,060
1994		*646*	16,262
1995		*652*	16,442
1996		*658*	16,380
1997		*665*	16,267
1998		*671*	16,319
1999		*677*	16,259
2000	1,222	*684*	16,718
2001		*690*	16,583
2002		696	16,611
2003			16,815
2004			16,769
2005			16,875
2006			16,962
2007			17,225
2008		745	17,462
% Change 1990-2000	49.7%	10.2%	8.0%



Williamsburg City

Year	RESAC / Woods Hole	Phase 5.2 Model	Popu-lation
1985		524	10,452
1986		*526*	10,669
1987		*527*	11,014
1988		*529*	11,154
1989		*531*	11,312
1990	507	*532*	11,600
1991		*534*	11,982
1992		*535*	12,307
1993		*537*	12,422
1994		*539*	12,301
1995		*540*	12,534
1996		*542*	12,241
1997		*544*	12,171
1998		*545*	12,363
1999		*547*	12,495
2000	601	*549*	11,998
2001		*550*	11,908
2002		552	11,627
2003			11,518
2004			11,648
2005			11,891
2006			12,176
2007			12,397
2008		636	12,481
% Change 1990-2000	18.5%	3.1%	3.4%

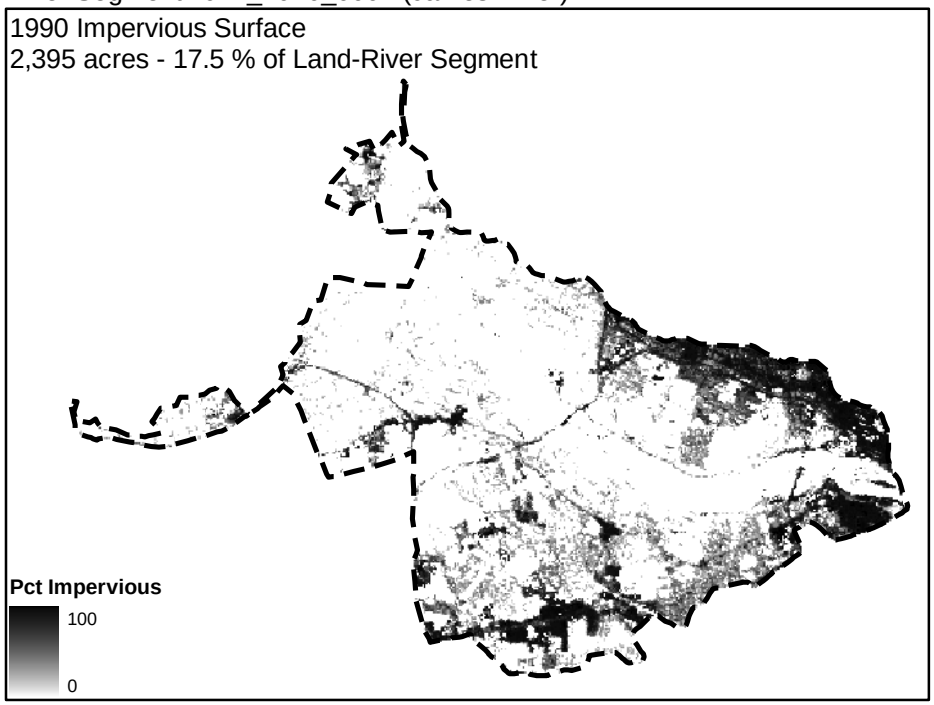
Appendix B: Analysis of RESAC Data Changes Between 1990 and 2000

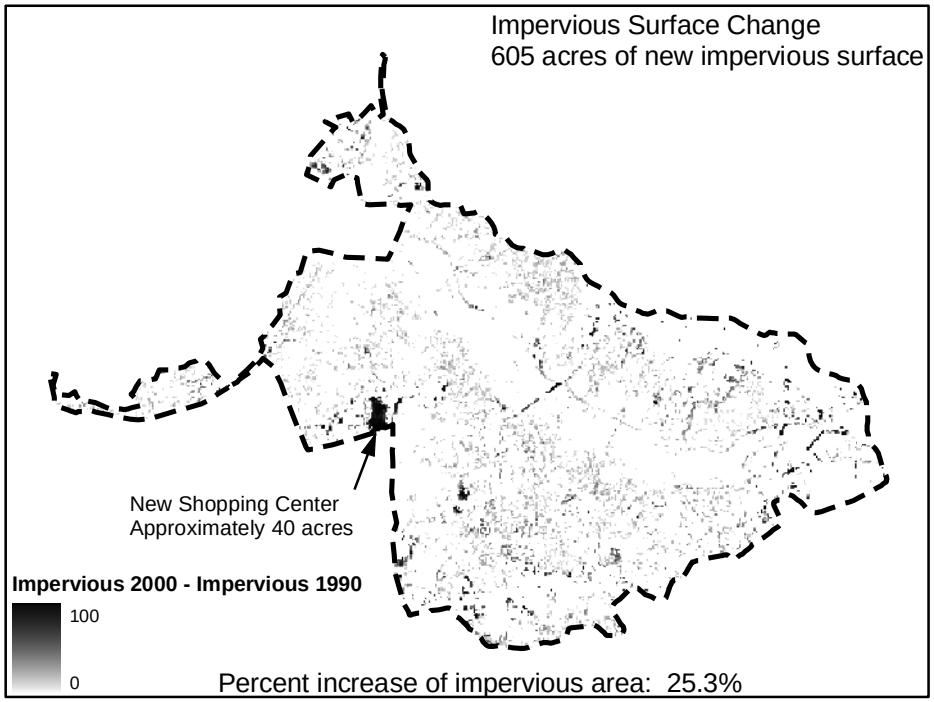
B1: City of Richmond, Virginia
B2: Study Area 1, City of Richmond, Virginia (Residential Development and Cemetery)
B3: Study Area 2, City of Richmond, Virginia (Powhite Parkway Bridge)
B4: Study Area 2, City of Richmond, Virginia (Reservoir Structure)

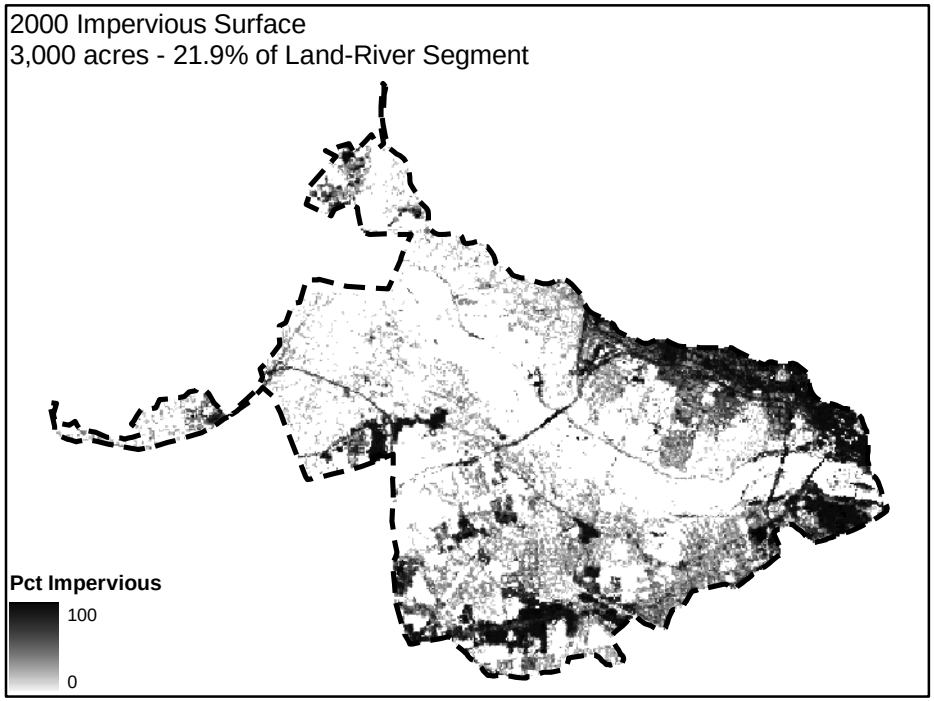
Appendix B: Analysis of RESAC Data Changes Between 1990 and 2000

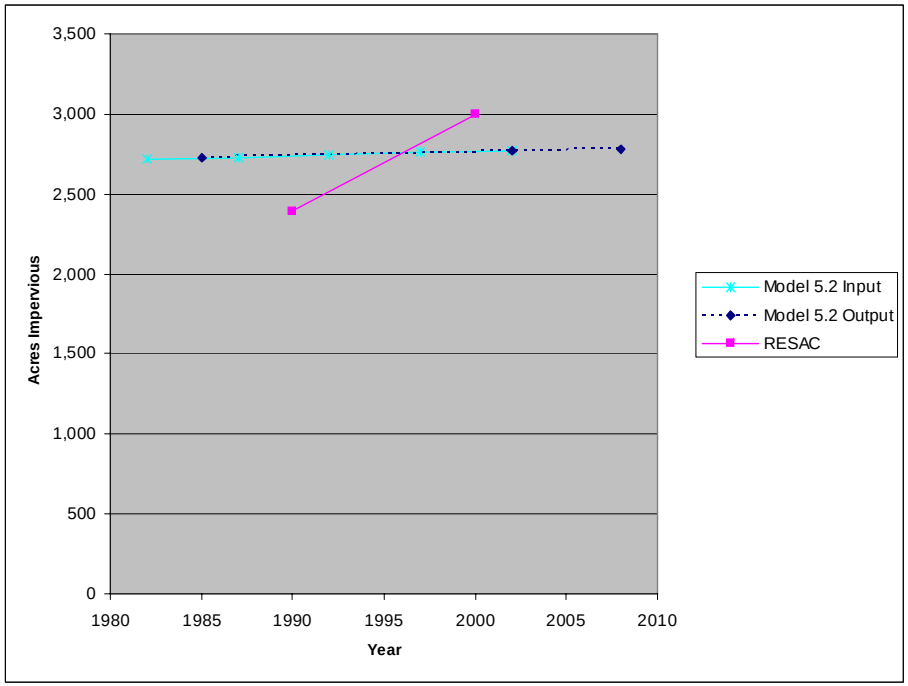
B1: City of Richmond, Virginia
B2: Study Area 1, City of Richmond, Virginia (Residential Development and Cemetery)
B3: Study Area 2, City of Richmond, Virginia (Powhite Parkway Bridge)
B4: Study Area 2, City of Richmond, Virginia (Reservoir Structure)

Appendix B1
Land Segment: 51760 (Richmond, VA)
River Segment: JL7_7070_0001 (James River)



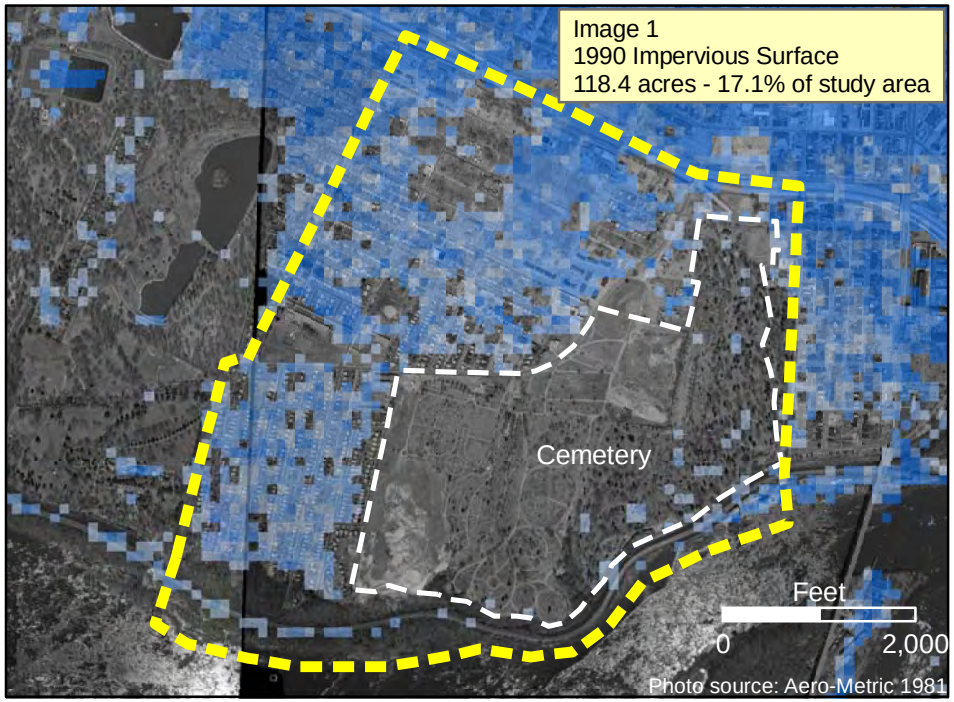


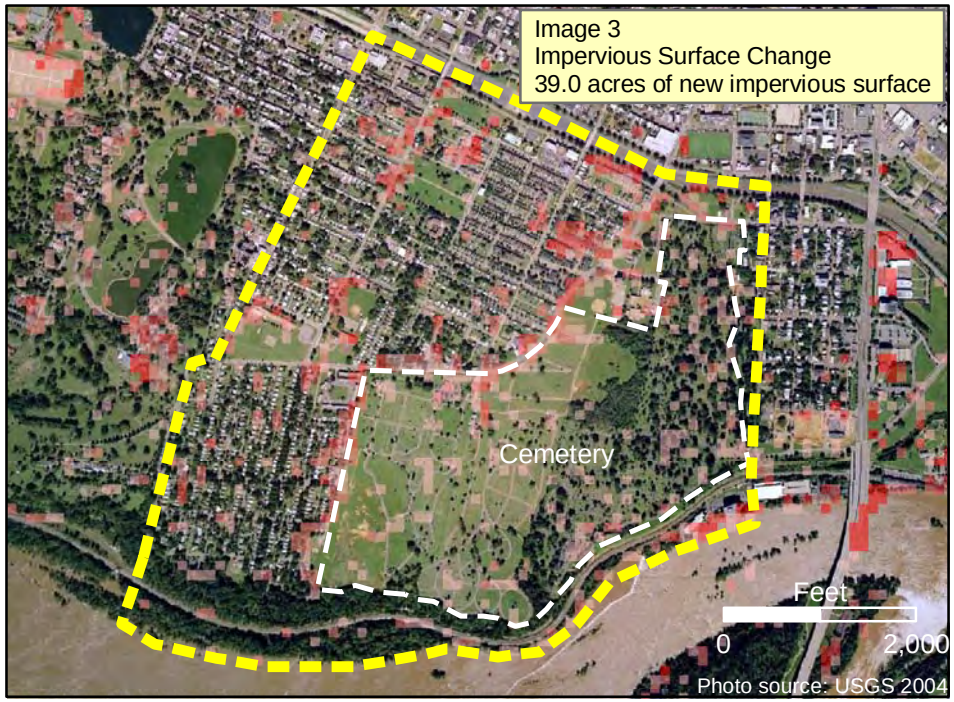




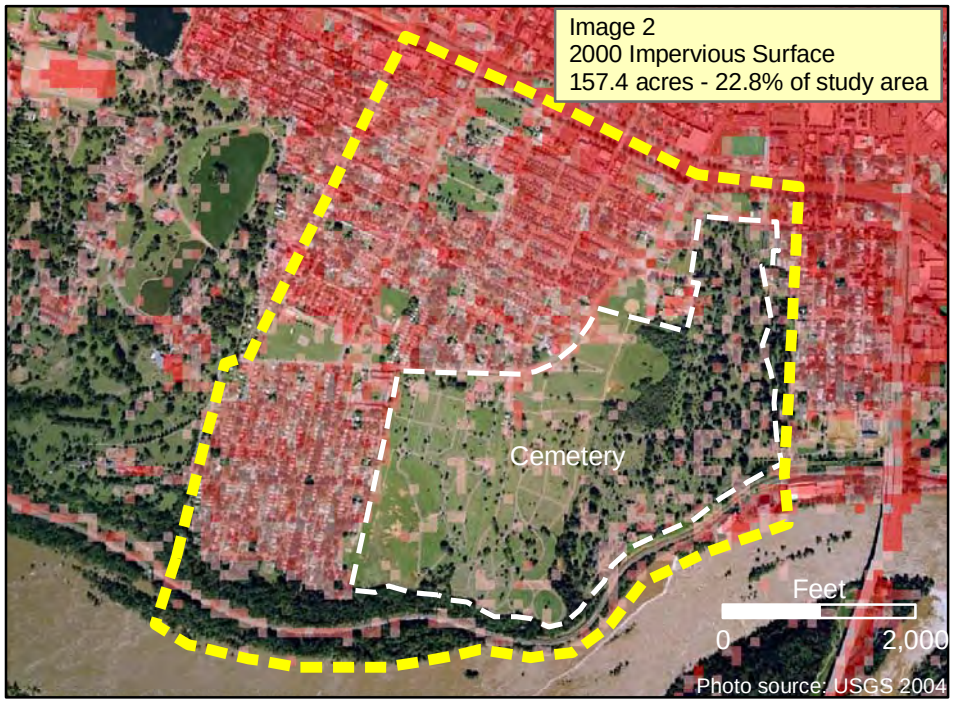
L:\21000s\21829.01\GIS\Impervious\Richmond.mxd

Appendix B2
Study Area 1 - Section of Richmond, VA





Percent increase of impervious area: 32.9%



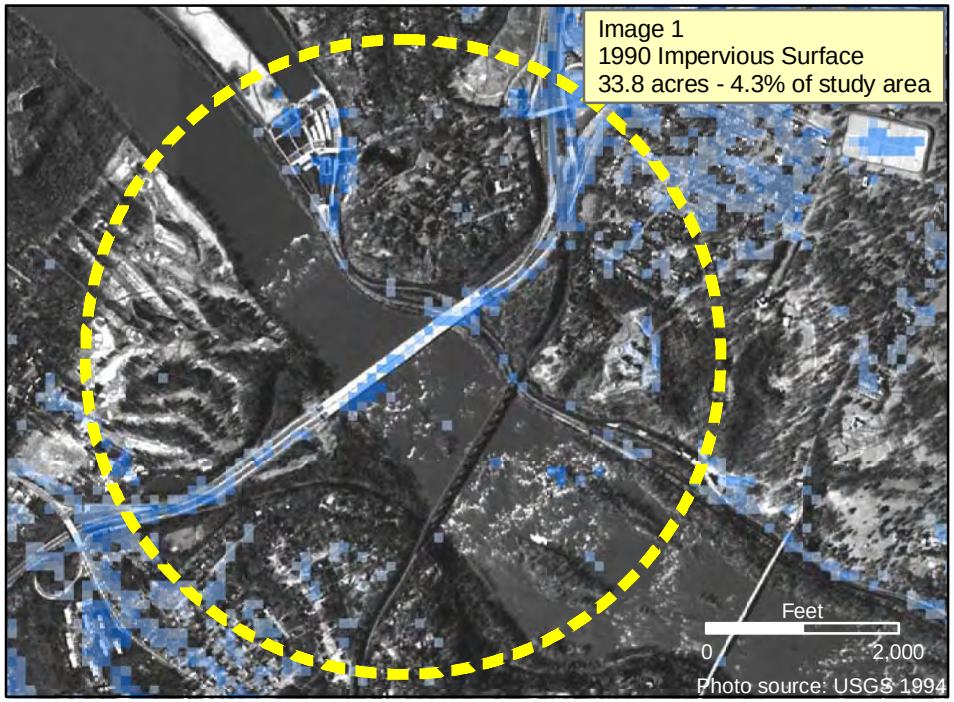
Year	Acres Impervious	Percent of Study Area
1990	118.4	17.1%
2000	157.4	22.8%
Change	39.0	5.6%

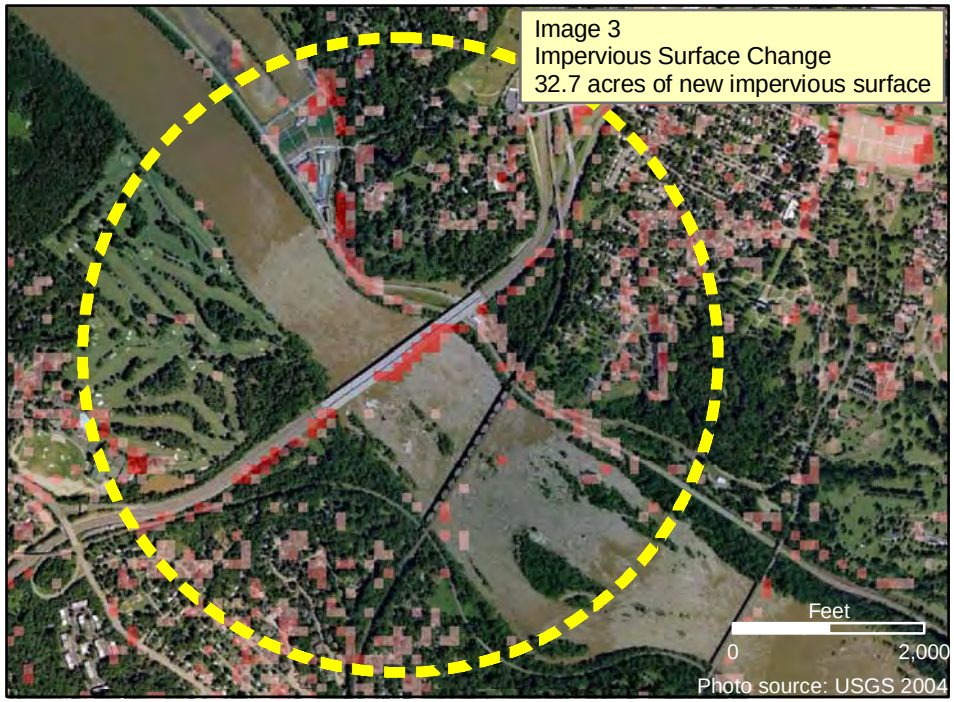
Total Study Area (acres): 691.6

Photo source: 2005 Aerials Express

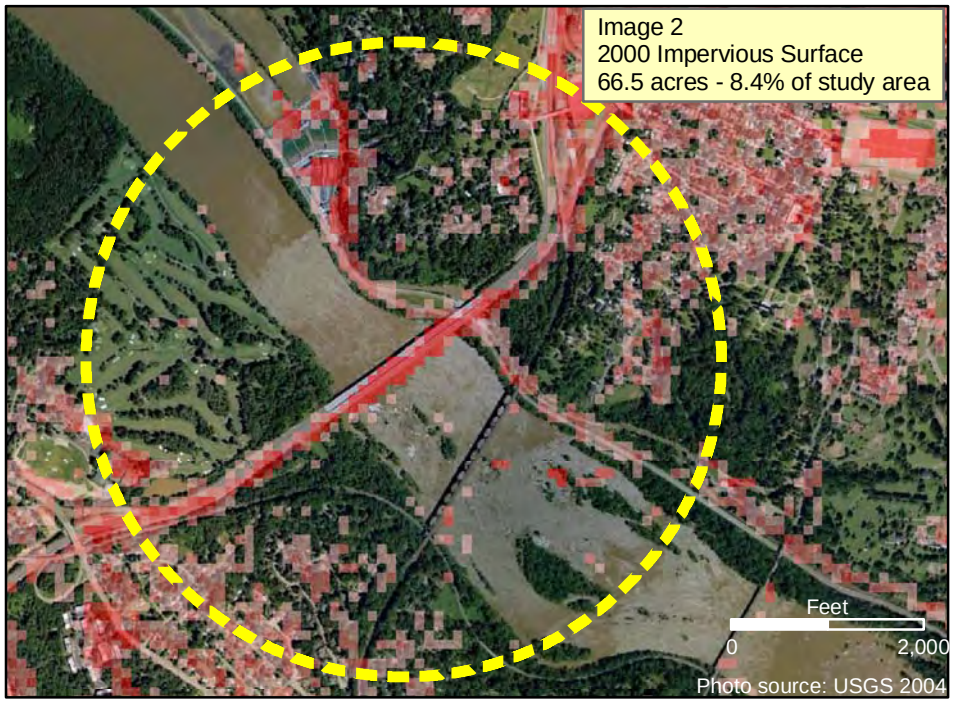
L:\21000s\21800\21829.01\GIS\Impervious\Richmond - Study Area 1.mxd

Appendix B3
Study Area 2 - Section of Richmond, VA (Powhite Parkway Bridge)





Percent increase of impervious area: 96.6%



Year	Acres Impervious	Percent of Study Area
1990	33.8	4.3%
2000	66.5	8.4%
Change	32.7	4.1%

Total Study Area (acres): 788.2

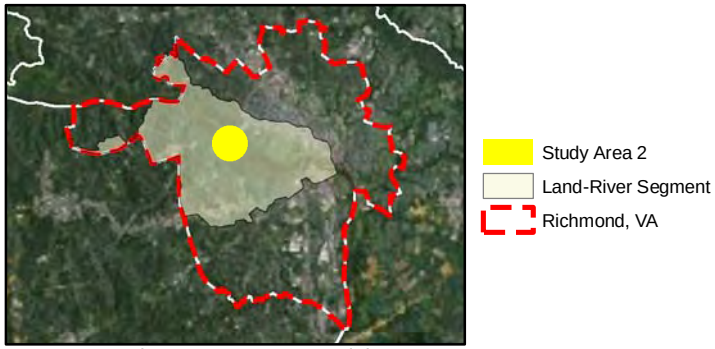
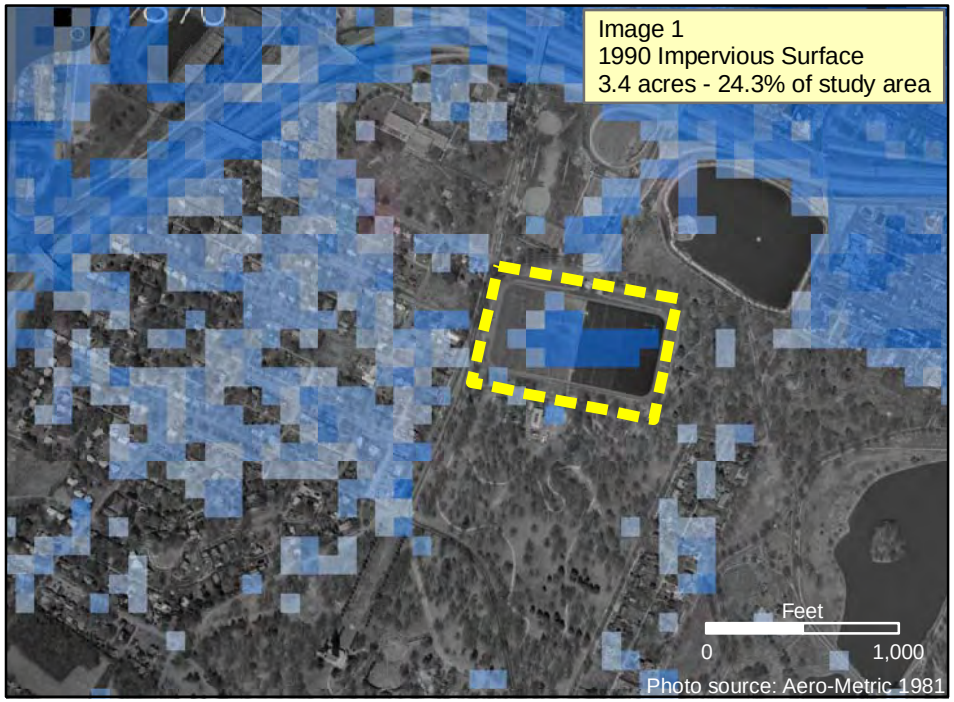
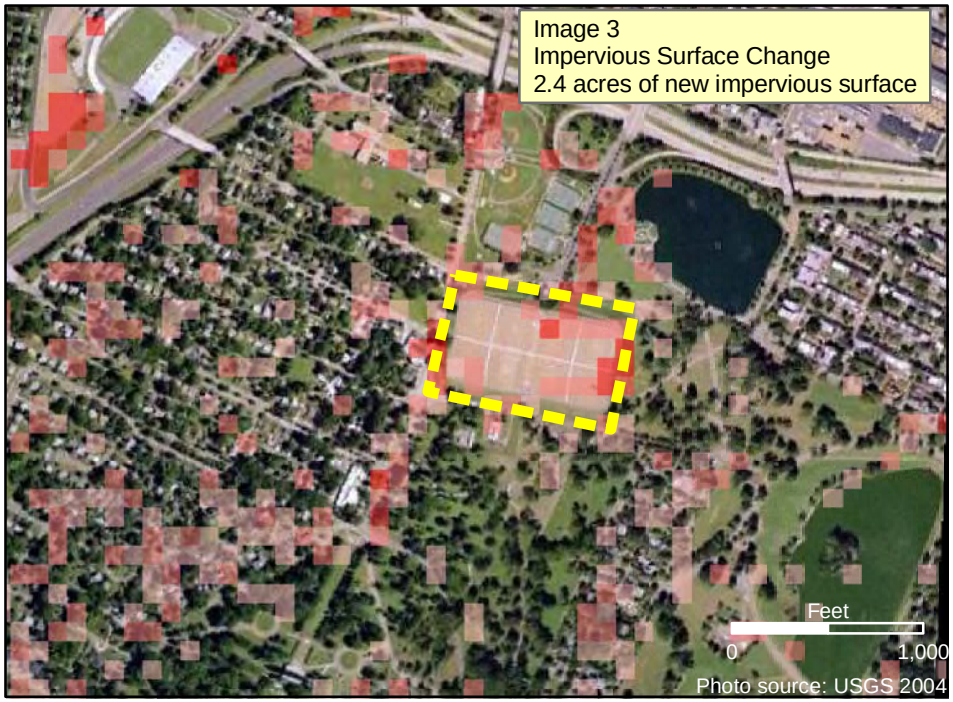


Photo source: 2005 Aerials Express

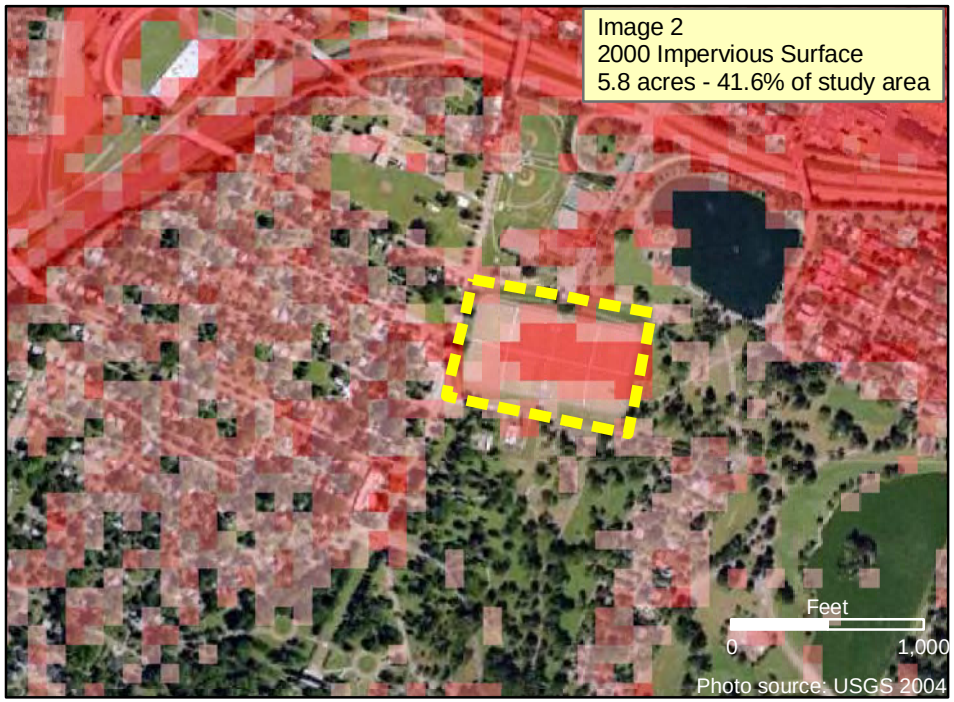
L:\21000s\21800\21829.01\GIS\Impervious\Richmond - Study Area 2.mxd

Appendix B4
Study Area 3 - Section of Richmond, VA





Percent increase of impervious area: 71.6



Year	Acres Impervious	Percent of Study Area
1990	3.4	24.3%
2000	5.8	41.6%
Change	2.4	17.4%

Total Study Area (acres): 13.9

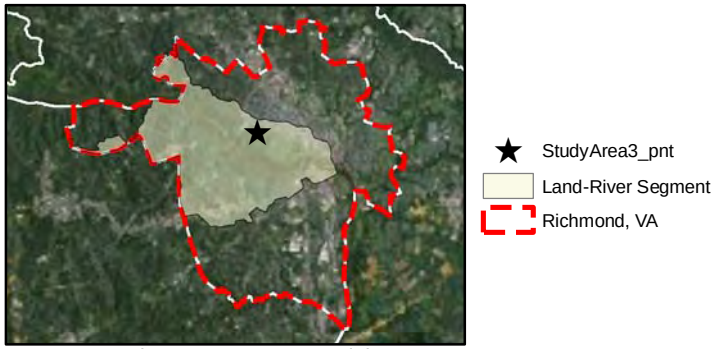


Photo source: 2005 Aerials Express

L:\21000s\21800\21829.01\GIS\Impervious\Richmond - Study Area 3.mxd