IMPROVE Completeness for Calendar Year 2001

Author: Robert Eldred, CNL, University of California, Davis (raeldred@ucdavis.edu)
Date: June 28, 2002

Why do we collect filters? In 1977, Congress designated 156 Mandatory Class I Federal Wilderness area across the United States to be protected from visibility impairment. It is possible to measure visibility impairment directly, but this provides no information on what is causing the impairment and does not lead to remediation. A more useful approach is based on the fact that visibility impairment is primarily produced by the scattering and absorption of particles suspended in the atmosphere. The amount of impairment depends on the composition and size of the particles. By measuring the composition of the particles it is possible to determine what general type of source is most responsible and permit remedial action. Currently, the best way to determine the composition and concentration of atmospheric particles is to collect the particles on filters and have the filters analyzed by several methods. The whole procedure is laid out in the Regional Haze Regulation.

Why do we need four modules? The particles that most affect visibility belong to five groups: sulfate, nitrate, organic, elemental carbon, and soil. At marine sites, we can add sodium chloride. Each group might contain many species. For example, there are thousands of possible organic species. Measuring all species is currently impossible; therefore, only the sum of all organic particles is monitored by measuring the carbon component. All of the major soil species are measurable (Al, Si, Ca, Ti, Fe), but for convenience these are combined with their expected oxides to produce the variable soil. The optimum analysis of all five groups of particles requires multiple filter types. Teflon is optimum for mass and for elements associated with sulfate and soil. Nylon is optimum for sulfate and nitrate ions. Quartz is needed for measuring organic carbon and elemental carbon. In addition to the composition of the particles, impairment depends on the particle size. Particles smaller that 2.5 micrometers ($PM_{2.5}$) are much more efficient at impairing visibility than larger particles. Thus, these five groups are only monitored in the $PM_{2.5}$ range. Coarse particles (defined as between 2.5 and 10 micrometers in diameter) are generally responsible for a small fraction of visibility impairment. Rather than measuring the composition of the course particles, IMPROVE only monitors the sum of all coarse particles, the coarse mass. This is obtained by subtracting the $PM_{2.5}$ mass from the mass of all particles smaller than 10 micrometers (PM_{10}). Thus four modules are needed, three that collect $PM_{2.5}$ particles on Teflon, nylon, and quartz filters, and one that collects PM_{10} particles on Teflon.

What is a valid measurement? To calculate the visibility impairment for each sample day, the first step is to multiply each of the six groups by a factor that reflects the efficiency of that type of particle for scattering and absorbing light. Then the six terms are added to give the visibility impairment for that day. To get a valid measurement, all six terms should be valid. For IMPROVE, this means that all four modules must collect valid samples.

How many valid samples do we need each year? To answer this, it is necessary to look at the way the visibility impairment of each day will be combined. Rather than simply using the average visibility impairment for a calendar year, the Regional Haze Regulation uses the average values for the clean days and the worst days. The worst days are defined as those with the upper 20% of impairment values for the year, and the clean days as the lower 20%. The annual values for each five-year block will be averaged, and trends examined. Three criteria have been set to determine the minimum number of daily samples needed to have a valid year. Because concentrations of the groups vary seasonally, there are both annual and seasonal criteria. The criteria are:

- 75% of the possible samples for the calendar year must be complete
- 50% of the possible samples for each calendar quarter must be complete
- No more than 10 consecutive sampling periods may be missing.

How did IMPROVE perform during the year 2001? Strictly, the Regional Haze Regulation only applies to the 110 sites that officially represent the 155 Mandatory Class I areas. Additional sites operated for the National Park Service, the Forest Service, states, and tribes will probably also use the same calculation. Therefore, no distinction is made between the two groups in this report. We considered only those sites that operated at least three months in 2001.

The median site had a 92% completion rate, which is excellent. Ninety percent of the sites had a completion rate greater than 75%, which is the annual criterion for acceptance. If we consider only the 103 sites were installed before January 2001, then 12 failed the annual criterion and 3 others failed the quarter or 10-consecutive criteria.

To help us understand why samples were lost, the reasons were broken down into the five categories of Table 1. This table also lists the average loss for the network and the median loss for each site Sometimes, these differ significantly. For example, although 2.8% of all possible samples for the network were lost because of equipment problems, more than half of the sites had no losses because of equipment problems.

Table 1. Reasons for lost samples.

category	description	average loss	median loss
not changed	The operator did not change the cartridges during the designated time period. In many cases, the operator did not indicate why this occurred.	3.7%	2.5%
bad change	The most common reasons were that the cartridge was installed upside down or the operator did not properly swap the cassette between cartridges when the change day fell on a sampling day.	1.5%	0%
equip-ment	The most common loss is from damage to the controller because of lightning-related power surges. UPS systems have been installed at the worst sites. Occasionally, the malfunction is not identified until the data validation check.	2.8%	0%
power outage	This indicates that the power was down for at least 8 of the 24 hours. Many of the sites are so remotely located that the power is not reliable.	2.5%	0.8%
other	This covers everything else. The most common reason is that one of the filters was damaged between being sent out and received.	1.0%	0.8%

How did sites perform individually? Table 2 gives the sites with an annual rate of greater than 75%, arranged in alphabetical order. The reasons are broken down into the five categories above. A blank indicates no sample was lost for that category. Table 3 gives the sites that failed the annual criterion and a comment for each site.

Table 2. Annual completeness for 2001 for sites with over 75% completeness. There were 122 possible sampling periods in 2001. Official IMPROVE sites representing Class I areas are indicated by an * . The columns are as follows:

"agency" This is the agency responsible for providing an operator.
"rank" The ranking within the 137 sites with over 31 possible samples.
"not changed" The operator did not change the sample at the designated time.
"bad change" The cartridge was installed incorrectly. In many cases, this occurred when Tuesday was a sampling day.
"equipment" Some component malfunctioned. In many cases, this followed electrical damage from power surges.
"power" Power was lost for at least 8 hours.
"other" The most common reasons were damaged filters and filter identification uncertainty.

site	agency	possible	complete	rank	not changed	bad change	equipment	power	other
Acadia *	NPS	122	99%	10					1%
Addison Pinnacle	state	91	97%	32					
Agua Tibia *	FS	122	84%	108	3%		6%	7%	1%
Arendtsville	EPA	87	98%	20					2%
Badlands *	NPS	122	99%	10					1%
Bandelier *	NPS	122	98%	21	1%	2%			
Big Bend *	NPS	122	82%	110	11%		7%		
Bliss *	FS	122	85%	101	2%	8%	2%	2%	1%
Bondville	EPA	100	95%	46		2%			3%
Bosque del Apache *	FWS	122	78%	118	6%	3%	11%	2%	
Boundary Waters *	FS	122	84%	103	7%	2%	4%	2%	
Bridger *	FS	122	95%	40	1%			3%	1%
Bridgton	state	96	99%	13				1%	
Brigantine *	FWS	122	89%	83	5%	2%	2%	1%	2%
Brooklyn Lakes	FS	122	94%	50	3%		2%	1%	
Bryce Canyon *	NPS	122	80%	113	5%	8%	4%		2%
Cabinet Mountains *	FS	122	97%	26	1%			2%	1%
Cadiz	EPA	100	78%	117	1%	5%	14%	2%	
Canyonlands *	NPS	122	88%	90	5%	6%		2%	
Cape Cod	state	91	95%	49	1%		1%	1%	2%
Cape Romain *	FWS	122	100%	1					
Casco Bay	state	91	99%	14			1%		
Chassahowitzka *	FWS	122	95%	40		2%			3%
Chiricahua *	NPS	122	98%	21	1%			1%	1%
Columbia Gorge east	FS	122	94%	50	1%	3%			2%

site	agency	possible	complete	rank	not changed	bad change	equipment	power	other
Columbia Gorge west	FS	104	91%	71	1%			6%	2%
Connecticut Hill	EPA	88	97%	33			1%	1%	1%
Craters of the Moon *	NPS	122	89%	83		5%	3%	3%	
Death Valley	NPS	122	100%	1					
Denali *	NPS	122	97%	26	1%		2%	1%	
Dolly Sods *	FS	122	92%	67		2%		5%	1%
Dome Land *	FS	122	76%	122	16%		1%	4%	2%
Everglades *	NPS	122	94%	50		5%			1%
Gates of the Mtns *	FS	122	94%	50	1%		3%	1%	1%
Gila *	FS	122	84%	103	1%	2%		10%	2%
Glacier *	NPS	122	87%	94		6%	3%	1%	3%
Grand Canyon *	NPS	122	80%	113	2%	2%	12%		2%
Great Basin	NPS	122	94%	50	2%	2%		2%	
Great Sand Dunes *	NPS	122	92%	67	3%	3%		1%	1%
Great Smoky Mtns *	NPS	122	98%	15		1%			1%
Guadalupe Mtns *	NPS	122	95%	40	2%			2%	
Haleakala *	NPS	122	87%	94	5%	2%	4%	1%	2%
Hawaii Volcanoes *	NPS	116	89%	81	3%	7%			2%
Hells Canyon *	FS	122	86%	97	2%	2%	7%		2%
Hercules-Glades *	FS	101	100%	1					
Hillside	state	83	84%	106	4%	7%	1%	2%	1%
Hoover *	FS	51	84%	107	2%		12%	2%	
Ike's Backbone *	FS	122	96%	34	4%				
Isle Royale *	NPS	122	91%	72	2%		2%	2%	3%
James River Face *	FS	122	93%	59	3%		1%	2%	
Jarbidge *	FS	122	84%	103	3%	5%		3%	4%
Joshua Tree *	NPS	122	89%	83	5%	5%			2%
Kalmiopsis *	FS	122	98%	15			2%		
Lassen Volcanic *	NPS	122	92%	67	2%		2%	3%	1%
Lava Beds *	NPS	122	87%	94	1%	9%	2%		1%
Linville Gorge *	FS	122	96%	34	4%				
Livonia	EPA	100	92%	66			7%		1%
Lone Peak	FS	81	78%	120	15%	2%		1%	4%
Lostwood *	FWS	122	97%	26			1%	2%	
Lye Brook *	FS	122	77%	121	4%		7%	6%	6%

site	agency	possible	complete	rank	not changed	bad change	equipment	power	other
M.K. Goddard	EPA	86	100%	1					
Mammoth Cave *	NPS	122	96%	34	2%		2%		
Medicine Lake *	FWS	122	85%	101	3%	2%	7%		3%
Mesa Verde *	NPS	122	88%	90	2%		6%	4%	
Mingo *	FWS	122	93%	63	3%		2%	2%	
Mohawk Mountain	state	32	100%	1					
Monture *	FS	122	93%	59	3%			2%	1%
Moosehorn *	FWS	122	89%	83	3%		6%	1%	2%
Mount Baldy *	FS	122	80%	116	8%			11%	1%
Mount Hood *	FS	122	96%	34	1%			2%	2%
Mount Rainier *	NPS	122	98%	21	2%				
Mount Zirkel	FS	122	97%	26	2%	1%			
North Absaroka *	FS	122	75%	124	7%	2%	7%	10%	
North Cascades *	NPS	122	93%	63	2%			6%	
Okefenokee *	FWS	122	96%	34			2%		2%
Olympic *	NPS	46	100%	1					
Pasayten *	FS	118	93%	62	3%		3%	1%	
Petrified Forest *	NPS	122	84%	108	4%	2%	2%	8%	1%
Phoenix	QA	83	89%	80	11%				
Pinnacles *	NPS	122	86%	97	1%		9%	2%	2%
Presque Isle	tribe	100	100%	1					
Proctor Research	state	107	98%	19		2%			
Quabbin Reservoir	state	91	88%	89	4%	2%	4%	1%	
Quaker City	EPA	81	100%	1					
Queen Valley	state	83	94%	58	1%			4%	1%
Redwood *	NPS	122	90%	75	7%				2%
Rocky Mountain *	NPS	122	100%	1					
Saguaro *	NPS	86	94%	57	1%	2%		2%	
Salt Creek	FWS	122	97%	26			2%	1%	
San Gorgonio *	FS	122	89%	78	7%	2%		1%	
San Pedro Parks *	FS	122	82%	110	10%	2%	4%	2%	
Sawtooth *	FS	122	90%	75	6%		2%	2%	
Seattle	QA	58	95%	47				5%	
Seney *	FWS	122	98%	15					2%
Sequoia *	NPS	122	96%	34	2%			2%	

site	agency	possible	complete	rank	not changed	bad change	equipment	power	other
Shenandoah *	NPS	122	89%	83	4%			7%	1%
Sierra Ancha *	FS	122	86%	97	6%	2%	2%	3%	1%
Sikes	EPA	95	88%	88			7%	3%	1%
Sipsey *	FS	122	81%	112	6%	2%		4%	7%
Snoqualmie Pass *	FS	122	97%	26	1%	2%			
Spokane Tribe	tribe	35	89%	82	11%				
Starkey *	FS	122	98%	21			1%	1%	1%
Sula *	FS	122	92%	67		2%		3%	3%
Swanquarter *	FWS	122	94%	50	2%		2%	1%	
Sycamore Canyon *	FS	122	88%	90	7%		2%	2%	
Theodore Roosevelt *	NPS	122	90%	75	2%		1%	7%	
Three Sisters *	FS	122	98%	15	1%		1%		
Tonto *	NPS	122	94%	50	4%	2%			
Trapper Creek-Denali	NPS	37	95%	48		5%			
Trinity *	FS	122	78%	118	8%	8%		6%	
UL Bend *	FWS	122	88%	90	8%	1%		2%	2%
Upper Buffalo *	FS	122	95%	40			2%	1%	2%
Virgin Islands *	NPS	122	86%	97	7%	4%	1%		2%
Voyageurs *	NPS	122	95%	40	2%			3%	
Washington DC	NPS	122	93%	59	1%	5%			1%
Weminuche *	FS	122	99%	10					1%
White Pass *	FS	122	89%	78	2%		2%		6%
White River *	FS	122	91%	72	1%		5%	3%	
Wichita Mountains *	FWS	98	97%	25	1%				2%
Wind Cave *	NPS	122	80%	113	6%		6%	7%	1%
Yellowstone *	NPS	122	91%	72	9%				
Yosemite *	NPS	122	95%	40	1%	2%		1%	1%
Zion *	NPS	122	93%	63	3%	2%		2%	

Simeonof *, San Gabriel *, Tuxedni *, and Saguaro west were not installed until the last quarter of 2001. They all had 100% completeness for this short time period. White Mountain * was installed in January 2002.

Consecutive Criterion: Bosque del Apache, Grand Canyon, and Pinnacles lost more than 10 consecutive samples.

Annual Criterion: The sites that failed the annual criterion are listed in Table 3. The lower portion discusses some of the reasons and what the status is as of June 2002.

Table 3. Annual completeness for 2001 for sites with less than 75% completeness. The lower portion indicates some of the reasons.

site	agency	possible	complete	no change	bad change	equipment	power	other
Breton *	FWS	122	75%	13%	7%		5%	
Great Gulf *	FS	122	72%	2%		23%	1%	2%
San Rafael *	FS	122	72%	21%	2%		4%	1%
Old Town	tribe	61	72%	13%	8%			7%
Caney Creek *	FS	122	71%	2%	5%	4%	17%	
Kaiser *	FS	61	66%	33%				2%
Point Reyes *	NPS	122	66%	5%	3%	20%	1%	6%
Shining Rock *	FS	122	66%	11%		16%	7%	
St Marks *	FWS	122	64%	7%		4%	23%	2%
Crater Lake *	NPS	122	61%	8%	7%	22%	2%	1%
Indian Gardens	NPS	122	60%	24%	2%		14%	
Wheeler Peak *	FS	122	56%	7%		34%	2%	
Cohutta *	FS	113	47%	11%	3%	28%	12%	
Capitol Reef *	NPS	122	45%	25%			29%	1%

site	comments
Breton *	Early operator scheduling problems. A new problem in 2002: when the operator tried to shift to daylight savings, he changed the date, thereby invalidating a large number of samples until problem was identified.
Great Gulf *	Mostly lost PM_{10} mass because of an equipment problem. Excellent performance in 2002.
San Rafael *	The operator problems have continued into 2002.
Old Town	Backup operator problem was resolved in June 2002 by using state personnel as backup.
Caney Creek *	60% of loses were from power outages because of a problem with the external line power. The problem was fixed in March 2002. We have had 24 consecutive samples with no power outages.
Kaiser *	We have been able to solve an original problem with year round access and power. However, an unacceptable number of samples are still being lost to the operator not making the change.
Point Reyes *	Mostly lost PM_{10} mass because of equipment problem. New problem in 2002: the junction box was flooded. External contractor called in, but the repair took several weeks.
Shining Rock *	Controller damaged by lightning. Later, a vacuum hose was damaged by a rodent. In 2002, another controller was damaged by lightning.
St Marks *	The site was subject to power outages because of using an old power line. The external wiring was repaired in 2002 and has had no power problems since then.
Crater Lake *	The inlet was bend by the snow load on roof. Repairing the bend and installing a heavy-duty inlet was delayed by the inaccessibility of the roof. Good recovery rate in 2002.
Indian Gardens	This site halfway down the canyon has had perennial operator problems as well as marginal line power. The park service will have to use resource management personnel from the rim to obtain acceptable recovery rates.
Wheeler Peak *	Site is subject to lightning surges. Four controllers and a UPS were sent during the year. No problems thus far in 2002.
Cohutta *	Power surges damaged controller several times. Lost additional samples because of power outages and financial problems. A new surge protector was shipped.
Capitol Reef *	The entire park is subject to daily power outages. The large fraction of samples not changed is still found in winter and spring 2002.

Predicting the Future. The recovery rate for a given year at a site will not necessarily predict that for the next year. One site that had 100% completeness in 2001 had a very poor recovery rate for a previous year. Several sites that failed the acceptance criteria in 2001 have done quite in the first five months of 2002. So far in 2002, the completeness rate has been slightly better than in 2001, as shown in Table 4. The only area that was worse was in the "not changed" category. Perhaps this reflects the fact that some operator have a difficult time reaching the sites in winter. Loses due to equipment problems and power outages are sharply down. The two are related in that the majority of equipment problems follow surges and power outages. At a few sites with marginal line power, we have been able to cut the loses by tapping into a better supply. We have also installed increasingly larger surge protectors. Our field manager, Pete Beveridge, is working on a system of decoupling the sampler from the line power at selected sites. This will allow the sampler to function better when the power is inadequate because of outages or lightning surges.

IMPROVE is vastly different than any other network. Most networks have sites in cities or towns with good access and reliable power. Because the IMPROVE network is charged with monitoring at wilderness areas, most of the sites are very remotely located. This affects operation in two ways. First, the operator often needs to drive long distances on difficult mountain roads to reach the sampler. In winter, this often requires snow cats. Second, line power at remote sites is more of a factor. While reliable power is taken for granted in towns and cities, many remote areas suffer from long transmission over inadequate lines. The power has been significantly upgraded at some sites, such as at St Marks NWR. There are still a few, such as Capital Reef, Utah, and Tuxedni, AK, that simply have no reliable line power in the region. Third, the frequent electrical storms at our mountain-top sites is a problem. Finally, sample changing is inherently more complicated by the conflicting demands by the Environmental Protection Agency for third-day-sampling and the land manager for weekly sample changes. The more complicated procedure when the sampling and change days coincide drops the recovery rate by about 1%.

Table 4. Comparison of average loss between the first half of 2002 with all of 2001.

category	Jan-Dec 2001	Dec 2001-May 2002	change
not changed	3.7%	4.0%	8% higher
bad change	1.5%	1.4%	7% lower
equipment	2.8%	1.8%	36% lower
power outage	2.5%	1.6%	36% lower
other	1.0%	0.5%	50% lower
total	11.5%	9.3%	19% lower

Appreciate the operators. What must not be lost in all the numerical details is that the vast majority of operators are doing an outstanding job.

Future Improvements. While the recovery rates are currently very good, all of us in the IMPROVE program want to decrease the losses even further. A tutorial will soon be out on the IMPROVE website that describes every step of sample changing and troubleshooting with detailed pictures. All operators will be given a calendar that marks the sampling days and makes Tuesday the most important day in the week. Steve Ixquiac and Pete Beveridge will continue to remind the operators that perfection is expected. The sampler system will continue to be upgraded to perform better with inadequate power and with power surges.

This report was presented to the IMROVE Steering Committee in June, 2002.