Air Quality

The Washington State Joint Legislative Audit and Review Committee (JLARC) conducted a review of the state's efforts to conserve habitat and expand outdoor recreation. This work included a review of existing or potential objective outcome measures that could be used to evaluate the success of 13 land acquisition and regulatory programs intended to protect and conserve habitat and expand outdoor recreation. Based on the effective outcome measures found in the peer-reviewed and gray literature, communications with managers from similar programs in the U.S., and the project team's professional opinion, it was found that there is very little literature that focuses specifically on outcome measures as they relate to land acquisition intended to protect and conserve species, habitats or to expand outdoor recreation; however a number of states and regions have implemented outcome measures for acquisition, and guidance is available from the extensive literature on restoration program and project effectiveness.

Introduction

Developing strategies to effectively measure ecological outcomes that are linked to specific programs and projects is an essential, but not simple, task that remains generally elusive in practice (Dale and Beyeler, 2001; Sawhill and Williamson, 2003; Niemi and McDonald, 2004; Doren et al., 2009; Margoluis et al., 2013). There are many examples of project-level effectiveness and projects that have laid out clear outcome measures linked to the project goals, such as Hartema et al. (2014). At the programmatic and regional levels, examples of these outcome measures are more difficult to find. For an example of a regional evaluation of the cumulative effectiveness of multiple projects see Diefenderfer et al. (2016). For a model-based evaluation of restoration project impacts at a watershed scale see Roni et al. (2010).

Some researchers note that the increased demand for outcome measurement, particularly ecological outcomes, does not imply that they are useful for decision making or that they are frequently used (Turnhout et al., 2007). Others argue that aligning outcome measures (indicators and metrics) with the mission and goals of an organization, program, or project can change it profoundly.

Margoluis et al. (2013) argue that to measure success in conservation three questions must be answered: (1) are we achieving our desired impact?; (2) have we selected the best interventions to achieve our desired impact?; and (3) are we executing our interventions in the best possible manner? Another question to add to this list is (4) who is the audience and who will care about the effectiveness of our program and our actions?

Outcome measurement processes are based on the selection of indicators and metrics, and the choice of indicators and metrics will directly impact the results of the process (Behan et al., 2017). To understand which indicators and metrics have been shown to effectively measure the performance of land acquisition and regulatory actions, we focused our efforts on peer-reviewed literature, agency publications, and on programs that would help provide information about 'best practices' for outcome measures that were not found in peer-reviewed or agency publications. By best practices we were looking for *outcome measures* (i.e., indicators and metrics) and programs that were effective, innovative, or promising.

Due to the complexity and nuances related to the protection of air quality and its variable impacts to different human communities and natural habitats in Washington, this section is not intended to be a comprehensive compendium of the indicators and metrics used to create effective outcome measures. Rather it is a compilation of effective outcome measures and practices based on our literature search, conversations with program managers, and the opinions of the project team within the timeframe of the project. The complete report (Behan et al., 2017) provides many more details concerning the development of outcome-based indicators from the literature, along with information on all of the other related programs and subject areas evaluated in the JLARC study.

Background

While the focus of this research was on habitat and species protection, air quality regulatory programs were identified as needing outcome-based indicators. Air quality regulations in the state of Washington are administered by the Department of Ecology, seven regional clean air agencies and various local authorities. The 1967 Washington Clean Air Act was significantly expanded and strengthened by the 1991 Clean Air Washington Act in response to 1990 revisions of the federal Clean Air Act (CAA), which stipulated that state air quality regulations must meet or exceed federal standards. These statutes are collectively referred to as the Washington Clean Air Act (WCAA) and are robust compared to those in most other states.

A State Implementation Plan (SIP) submitted to the U.S. Environmental Protection Agency (EPA), describes how the state implements, maintains, and enforces National Ambient Air Quality Standards and other CAA tenets. As required by the CAA, the Department of Ecology, EPA, tribes, and regional clean air agencies monitor “criteria” pollutants- carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter ($PM_{2.5}$ and PM_{10}), and sulfur dioxide – via a network of about 70 monitoring stations statewide. The EPA also tracks 187 pollutants referred to as airborne toxics, which are known to cause cancer and other serious health impacts.

The Washington Forest Practices Act, administered by the Washington Department of Natural Resources (DNR), includes a statutory goal of “protecting air quality” on public and private commercial non-federal and non-tribal state forestland. One of the main sources of air pollution in Washington is wood smoke. Forest practice impacts on air quality are primarily carbon monoxide (CO), particulate, and volatile organic compound (VOC) emissions from controlled burning of logging slash and residues from wildfire fuels reduction efforts. Forest practices also produce dust and exhaust emissions from vehicles and harvesting equipment. The 1991 revision of the WCAA significantly curtailed open burning of biomass, including logging slash.

Washington’s forests sequester huge amounts of carbon. Wildfires release carbon as CO, along with particulates and ozone-forming VOCs. The ways in which forest practices affect wildfire risk, and in turn, relationships between sequestered carbon, atmospheric carbon, air quality and climate change are very complex, difficult to quantify with certainty, and currently the subject of much research and debate. Managers often face stiff opposition to controlled burning due to smoke emissions, even though such efforts can reduce the risk of large wildfires that emit many times as much smoke, but these tradeoffs are also beyond our current ability to quantify with any certainty.

Outputs

A short list of outputs identified in agency materials, or provided by JLARC, about the programs relevant to air quality:

- Attainment Plans for areas that do not meet NAAQS standards; maintenance plans for areas that have been brought into attainment
- Plans for programs required by the CAA, e.g., the Motor Vehicle Inspection & Maintenance Plan, the Washington State Visibility Protection Program and the 1998 Smoke Management Program

Outcome statements

The primary outcomes the project team identified from the objectives in the enabling legislation of the program:

- Prevent air pollution from reaching levels that impact human health or air quality meeting or exceeding NAAQS and standards
- Healthier air quality; fewer days of unhealthy air quality
- Fewer air quality-related health problems and impacts for Washingtonians
- Reduced environmental damage to species and property
- Healthier ecosystems
- Reduced haze, and improved visibility, especially in parks and wilderness areas

Literature

By almost any measure, implementation of the Clean Air Act has resulted in dramatic reductions in air pollution since the 1970s. Yet air pollution continues to harm people and the environment. Today, in Washington and many other areas, particulates (PM_{10} - respirable particulate matter; $PM_{2.5}$ –fine particulate matter) and ground-level ozone are the pollutants of greatest concern because they influence human health the most. The pollutant of concern varies by location due to influences such as population density, economic activity, meteorology, and the landscape characteristics that affect airflow. These factors also influence which strategies are likely to succeed in controlling pollution.

Population and the resulting traffic are the primary sources of CO pollution in the Puget Sound area, while windblown dust is a major contributor to particulate problems in eastern Washington. Just as there are numerous pollutants, there is also a range of ways to measure and express air quality. The best measure to use depends on the issue at hand. For example, day-to-day variations in levels of some air pollutants are known to correlate with emergency room visits by children with asthma. In this case, tracking this day-to-day variation would be relevant. By contrast, if the issue is long-term cancer risk, annualized average concentrations of airborne toxics would be more useful.

Air quality is widely and conclusively known to impact human health. But directly measuring the health benefits of air quality regulations is challenging because it is difficult to correlate pollution reductions to regulations, because trends are slow to emerge as a result of lags in technology adoption and interacting effects that can obscure change such as weather, population growth, or behavior changes. Further, pollution reductions can occur over large spatial ranges, well outside any state. As a result of these complicating factors, sophisticated models are typically used to project health benefit changes from regulation, rather than direct measurements.

Because the correlations between air pollution and health are well documented, they provide strong support for tracking changes in pollutant levels as a leading indicator of health benefits. Emissions levels of pollutants are an important indicator of air quality, but do not give accurate picture of levels that people are actually exposed to. Ambient air concentrations are better for demonstrating effectiveness.

An option for tracking ambient concentrations is the AirNow system developed by the EPA, National Oceanic and Atmospheric Administration, National Park Service, tribal, state, and local agencies to provide public access to air quality information. State and local agencies report the air quality index (AQI) for cities across the US and parts of Canada and Mexico. The higher the AQI value (0-500), the greater the pollution level and health concern. AQI values below 100 are generally considered satisfactory; above 100, air quality is considered to be unhealthy-at first for certain sensitive groups of people, then for everyone as AQI values get higher (EPA 2016).

Each day, monitors record concentrations of major pollutants at over a thousand locations nationwide. These raw data are converted into a separate AQI value for each pollutant (ground-level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide) using formulas developed by EPA. The highest of these AQI values is reported as the AQI value for that day. The Washington Air Quality Advisory is similar to the AQI, but has a stricter standard for fine particulates ($PM_{2.5}$).

A model for projecting health outcomes is BenMAP-CE, an open-source GIS based computer program that calculates the number and economic value of air pollution-related deaths and illnesses. The software incorporates a database that includes many of the concentration-response relationships, population files, and health and economic data needed to quantify these impacts. BenMAP-CE uses "health impact functions" constructed using information from the published epidemiology literature. A health impact function incorporates four key sources of data: 1) modeled or monitored air quality changes; 2) population; 3) baseline incidence rates; 4) an effect estimate. BenMAP estimates changes in the number of illnesses and deaths that could occur in a population if air pollution levels were reduced by a specified amount (Driscoll et al., 2015).

In practice

Direct outcome goals and measures for air quality regulations are usually quantified as the percentage of time that the NAAQS standards are met and degree of improvement toward attainment of those standards. States also use modeling, and later monitoring, to demonstrate that ambient air quality will not be degraded when new power plants point sources of pollution are built. Less commonly, those ambient standards are translated via models into a variety of measures related to diseases or medical conditions associated with, or aggravated by air pollution.

Emissions are an important indicator, but do not give accurate picture of levels of pollutants that people are actually exposed to. Ambient air concentrations are better for this, since they reflect people's exposure. Because of this, many states and municipalities establish air quality monitoring networks to measure this, and a number of recent papers have reviewed the outcome-based indicators for the effectiveness of these networks (Pope and Wu, 2014; Scheffe et al., 2009).

Air quality indicators and metrics identified in the literature are included in Table 1 (below).

Conclusions

Methods for developing meaningful outcome-based indicators are clearly identified in the literature. They are being put into practice successfully in a few states, but generally very sparsely across the country. Rarely are they done for species and habitat focused land acquisition programs, although these are widely developed for air quality.

The most effective programs for evaluating program success in land acquisition, water quality protection, and restoration, and air quality had a few commonalities. First, the legislation that created these programs was relatively specific in describing the types of outcomes desired, so designing an outcome based set of indicators was more straightforward for agencies. Second, the legislation required that indicators of program success be developed and reported on some regular schedule, and at a minimum funded the development of the indicators and their implementation, often requiring interagency cooperation, which is essential as many agencies and local or regional governments may be involved in program implementation. And lastly, they required statewide (or jurisdiction wide for regional governments such as Tahoe) evaluation of outcomes – which helps to assure the development and measurement of the indicators are not focused on plans, projects, or problem areas. To understand if regulatory programs are protecting air quality in Washington, it is critical to have a reasonable understanding of the baseline conditions in all areas in the state. Without this information, it is impossible to understand if any existing programs are making a difference. Statewide assessments are necessary to understand statewide outcomes. A plan or strategy to address local source of pollutants is an important way to understand and fix a problem. But the strategy is not necessarily the information needed to describe the status and trends of air quality in the state or region, which are the primary goals identified in the law.

Table 1. Indicators and metrics for air quality outcomes identified in the literature or effective practices

Categories	Indicators and Metrics (Units of Measurement)	Source(s)
Visibility	*Visual range* • # of miles or kilometers the naked eye can see • Extinction coefficient , e.g.' California standard for this measure is 8-hour avg. extinction coefficient of 0.07/kilometer – visibility of 30 miles or more due to particles when relative humidity is <70%. • IMPROVE algorithm (Interagency Monitoring of Protected Visual Environments) to estimate light extinction, which is then converted to the deciview haze index	Latimer et al., 1981; Richards, 2011; Uhl and Moore, 2017
Wildfires and Smoke	• Acres of forest land burned annually by wildfire • Length of wildfire season • Days of community smoke avoidance warnings	Uhl and Moore, 2017
Other	*Other indicators and metrics* • Lichen – Trends in population of lichens, which are very sensitive to air pollution	Jovan, 2008

Table 1. Indicators and metrics for air quality outcomes identified in the literature or effective practices (continued)

Categories	Indicators and Metrics (Units of Measurement)	Source(s)
NAAQS and Other Standards	*Non-attainment criteria pollutant(s)* • $PM_{2.5}$ (particulate matter 2.5 micrometers or less in diameter), PM_{10} (particulate matter 10 micrometers or less in diameter), and ozone • Trend in the annual number of days in which the EPA Air Quality Index (AQI) exceeds 100 over the past 5 years • Days above regulatory standard (ozone and particulates) • # of 24-hr periods exceeding the applicable federal or state standards at any monitoring station *PM_{10} (particulate matter 10 micrometers or less in diameter)* • Annual average PM_{10} concentrations at any permanent monitoring station *Ozone* • % of time ozone concentrations are at or below 0.09 parts per million averaged over 1 hour • % of time ozone concentrations are at or below 0.07 parts per million averaged over 8 hours • # of days in which the daily maximum 8-hour average ozone concentration exceeds a standard • Daily maximum 8-hour ozone concentrations *Nitrogen dioxide (NO_2)* • % of time NO_2 concentrations are at or below 53 parts per billion averaged over 1 year (Federal standard) • % of time NO_2 concentrations are at or below 30 parts per billion averaged over 1 year (California standard) • *Carbon monoxide (CO)* • % of time CO concentrations are at or below 6 parts per million averaged over 8 hours	EPA, 2016; Pope and Wu, 2014; Driscoll et al., 2015
Human Health	*Cancer risk* • Community's total cancer risk from hazardous air pollutants is less than 50 per million • Trend in the total cancer risk from hazardous air pollutants in the community over time • National Air Toxics Assessment (NATA) total lifetime cancer risk attributable to air pollution *Other health risks* • Measured reductions in mortality after measured improvements in air quality • # of emergency room visits by children with asthma (per day, per year) • # of emergency room visits by older adults with respiratory problems (per day, per year) • # of person-days that a region has unhealthy air. Person-days: The number of persons living in an exposed region X the number of days the pollutant exceeds a health standard (indication of the population burden of air pollution exposure) • Rank on list of national counties with the highest health risks due to diesel particulates • Trends in asthma rate and prevalence • % of schools and daycare facilities within 500 feet of busy roadways • Collated data points from GPS devices embedded in inhalers of people with asthma to identify clusters of inhaler use- indicator of areas with particularly bad air quality • BenMAP-CE health impact functions *Pollutant concentrations* • Contamination of human milk, parts per billion in fat • Maximum levels of pollutant in a given time period • Averages of pollutant concentrations in a given time period • # of days the pollutant exceeds a standard in a given time period	Pope and Wu, 2014; Scheffe et al., 2009

Citations

Behan, J., L.J. Gaines, J.S. Kagan, M. Klein, M., and L. Wainger. 2017. Outcome Measures for Habitat and Recreation Land Acquisition and Regulatory Programs: A Science-based Review of the Literature. Institute for Natural Resources, OSU, Corvallis, OR.

Dale, V.H. and S.C. Beyeler, 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

Diefenderfer, H.L, G.E. Johnson, R. M.Thom, K.E. Buenau, L.A. Weitkamp, C.M. Woodley, A.B. Borde, and R. K. Kropp. 2016. Evidence-based evaluation of the cumulative effects of ecosystem restoration. *Ecosphere* 9(3): e01242. DOI: 10.1002/ecs2.1242.

Doren, R.F., J.C. Trexler, A.D. Gottlieb and M.C. Harwell. 2009. Ecological indicators for system-wide assessment of the greater everglades ecosystem restoration program. *Ecological Indicators* 9s:s2-s16.

Driscoll, C.T., J.J. Buonocore, J.I. Levy, K.F. Lambert, D. Burtraw, S.B. Reid, H. Fakhraei, and J. Schwartz. 2015. US power plant carbon standards and clean air and health co-benefits. Nature Climate Change Vol. 5: 535-540. DOI: http://www.nature.com/doifinder/10.1038/nclimate2598

Environmental Protection Agency. 2016. *Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI)*. U.S. EPA, Research Triangle Park, NC. 23 pp. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P29X.PDF?Dockey=P100P29X.PDF

Hartema, L., J. Latterell, H. Berge, D. Lantz, and C. Gregersen. 2014. *Lower Boise Creek Channel Restoration Project 2013 Monitoring Report*. King County Department of Natural Resources and Parks Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/water-and-land/habitat-restoration/lower-boise-creek/boise-creek-monitoring-report-2013.pdf.

Jovan, S. 2008. *Lichen Bioindication of Biodiversity, Air Quality, and Climate: Baseline Results From Monitoring in Washington, Oregon, and California*. 2008. USDA Forest Service, PNW-GTR-37, 124 pp.

Latimer, D.A., H. Hugo, and T.C. Daniel. 1981. The effects of atmospheric optical conditions on perceived scenic beauty. *Atmospheric Environment* 15: 1865-1874. doi.org/10.1016/0004-6981(81)90222-5

Margoluis, R., C. Stem, V. Swaminathan, M. Brown, A. Johnson, G. Placci, N. Salafsky, and I. Tilders. 2013. Results Chains: a Tool for Conservation Action Design, Management, and Evaluation. *Ecology and Society* 18(3): 22.

Niemi, G. and M.E. McDonald. 2004. Application of ecological indicators. *Annual Review of Ecology, Evolution and Systematics*. 35:89–111.

Pope, R. and J. Wu. 2014. A multi-objective assessment of an air quality monitoring network using environmental, economic, and social indicators and GIS-based models. *Journal of the Air & Waste Management Association* 64 (6): 721-737. http://dx.doi.org/10.1080/10962247.2014.888378

Richards, L. W. 2011. Use of the deciview haze index as an indicator for regional haze. *Journal of the Air & Waste Management Association* 49(10): 1230-1237. http://dx.doi.org/10.1080/10473289.1999.10463911

Roni, P., G. Pess, T. Beechi, and S. Morley. 2010. Estimating changes in coho salmon and steelhead abundance from watershed restoration: How much restoration is needed to measurably increase smolt production. *North American Journal of Fisheries Management* 30(6): 1469-1484.

Sawhill, J.C. and D. Williamson. 2003. Mission impossible? Measuring success in nonprofit organizations. *Nonprofit Management and Leadership* 11(3): 371-386.

Scheffe, R.D., P.A. Solomon, R. Husar, T. Hanley, M. Schmidt, M. Koerber, M. Gilroy, J. Hemby, N. Watkins, M. Papp, J. Rice, J. Tikvart, and R. Valentinetti. 2009. The National Ambient Air Monitoring Strategy: Rethinking the role of national networks. *Journal of the Air & Waste Management Association* 59(5): 579-590. http://dx.doi.org/10.3155/1047-3289.59.5.579

Turnhout, E., M. Hisschemöller, and H. Eijsackers. 2007. Ecological indicators: between the two fires of science and policy. *Ecological Indicators* 7(2): 215-228.

Uhl, M., and T. Moore. 2017. Visibility, haze, and background air pollution in the West. *Environmental Manager Magazine*. January. Air & Waste Management Association. https://www.wrapair2.org/pdf/uhl.pdf