

An Annotated Bibliography for LakeSmart 2.0

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In the fall of 2019, Maine Lakes Society staff undertook a literature review focused on the elements that are part of current LakeSmart evaluations. The goal of the literature review was to summarize recent peer-reviewed and grey literature, and apply any pertinent information to the revision of our LakeSmart standards, especially those standards likely to be impacted by climate change. This bibliography is by no means exhaustive, rather we focused on reviews in the areas of interest to LakeSmart in the following four three areas:

- Lakes, Water Quality, and Climate Change (p. 1)
- Human Behavior and Effects on Water Quality (p. 4)
- Nonpoint Source Mitigation Strategies (p. 6)
 - Structures and Septic Systems (p. 7)
 - Driveways (p. 8)
 - Lawns and Buffers (p. 8)

This version of the bibliography is meant to inform the LakeSmart committee and others working in lake conservation about recent literature developments.

Lakes, Water Quality, and Climate Change

Beyene, M.T. and Jain, S. (2015). Wintertime weather-climate variability and its links to early spring ice-out in Maine lakes. *Limnology & Oceanography*, 60: 1890-1905.

Climate studies are crucial when considering lake quality, and development is not the only stressor on water quality. Ice out dates are shifting earlier and warming is forecasted to continue by IPCC. Statistical analysis was performed on historical ice-out and weather data (1950-2010) of 8 Maine lakes. The results indicated that large scale inter-annual weather events have effect on ice out dates along with local climate. The results are significant because longer ice out periods are known to increase algae blooms in the arctic.

Coffey, R., Paul, M.J., Stamp, J., Hamilton, A., and Johnson, T. (2019). A Review of Water Quality Responses to Air Temperature and Precipitation Changes 2: Nutrients, Algal Blooms, Sediment, Pathogens. *Journal of the American Water Resources Association*, 844– 868.

Climate change will have cascading effects. This review of peer reviewed and grey literature post 2000, focused on changing air temperature and precipitation effects on

nutrients, algae blooms, sediment, and pathogens. Warm temperatures increase nutrient (nitrogen and phosphorus) availability, which precipitates mobile nutrients. Anticipated increases in temperature and precipitation could increase the risk of eutrophication. Eutrophication, nutrient precipitation, and warmer water temperatures could each drive toxic algae blooms. Known drivers of increased sediment are precipitation, along with land use, management, and vegetation (buffer). Intense rainfall increases erosion, leading to more sediment suspended in water. Many studies in the northern and eastern U.S. suggest a risk of increased annual loads. The reviewers end with an emphasis and call for research on BMPs and their effectiveness in meeting necessary management requirements in a changing climate.

Canfield Jr., D. E., Bachmann, R. W., Stephens, D. B., Hoyer, M. V., Bacon, L., Williams, S., & Scott, M. (2016). Monitoring by citizen scientists demonstrates water clarity of Maine (USA) lakes is stable, not declining, due to cultural eutrophication. *Inland Waters*, 6:1, 11-27

Maine lakes are often judged by non-scientists by their clarity. Scientists used secchi disk measurements taken by citizen scientists (VLMP), water quality measurements taken by Maine DEP staff, and satellite data taken by the USEPA in the 1990s to find seasonal changes and overall trends in water clarity. Color and chlorophyll affect the secchi depth readings. Results indicate that, on average, lakes are not changing. There was a small but statistically significant upward trend in secchi disk reading 1976-2013, indicating lakes are in fact becoming clearer. These results directly contradict McCullough et al. (2013), suggesting McCullough et al. had a limited data set that was not large enough to derive overall trends. Because lakes are on average staying the same, researchers suggest targeting problematic lakes rather than all lakes.

Giri, S and Z Qui. 2016. Understanding the relationship of land uses and water quality in Twenty First Century: A review. *Journal of Environmental Management*. 173:41-48.

Studies show agricultural practices such as tillage and fertilization increase nutrients in runoff which may eventually enter the watershed. Studies also show that altering the physical landscape for urban development increases impervious surfaces that do not infiltrate runoff. Most studies have modeled water quality, rather than monitoring it. The review defines and compares indices, methods, and variables used in the models. Statistical modeling is more widely used than the more complicated hydrological water quality model. Studies in North America have found a positive correlation between land use change and water quality degradation.

Kaushal, S., P., Mayer, P., Vidon, R., Smith, M., Pennino, T., Newcomer, S., Duan, C., Welty, & Belt., K. (2014) Land use and climate variability amplify carbon, nutrient, and contaminant pulses: a review with management implications. *JAWRA*. American Water Resources Association, Middleburg, VA, 50(3):585-614,

A review of how land use and climate variability amplifies unwanted contaminants in watersheds that includes a discussion of new research questions. There is a significant

base of research which states climate will become more variable, and other research models that predict more intense and frequent storms. Even though watersheds vary drastically, this review indicates that most watersheds respond more or less similarly to climate changes. The pulses of nutrients amplified by land use and climate variability “now require strong management actions.” Multiple studies show the effectiveness of a buffer is a function of width, plant content, and landform.

McCullough, I. M., Loftin, C. S. & Sader, S. A. (2013). Landsat imagery reveals declining clarity of Maine's lakes during 1995–2010, *Freshwater Science* 32(3), 741-752

Clarity is a strong indicator of water quality, and it can be used by the general public to determine water quality. Satellite measurements of lake clarity were taken in late summer. While the lakes were studied for 15 years, only 6 years produced usable data. The data showed a decline in lake clarity. The data shows that lakes in the northeastern and western portions of maine have declined disproportionately in relation to the average maine lake. This work contradicts Canfield et al. (2016), who claim that limited usable data taken during the 6 years is not enough to determine long term trends.

Moore, M. V., Pace, M. L., Mather, J. R., Murdoch, P. S., Howarth, R. W., Folt, C. L., & Driscoll, C. T. (1997). Potential effects of climate change on freshwater ecosystems of the New England/Mid-Atlantic region. *Hydrological processes*, 11(8), 925-947.

This review has a lot of information and references on predictions including: more extreme weather conditions, dryer overall climate, increased acidification of freshwaters due to large storms, increased toxicity of metals and algae, and fragmented habitat. Their prediction of a dryer climate contradicts others who state that more extreme weather will counteract dry spells and lead to an overall wetter climate. They recommend increased and improved research.

Nie, J., Gang, D.D., Benson, B.C. and Zappi, M.E. (2012). Nonpoint Source Pollution. *Water Environment Research*, 84: 1642-1657. doi:10.2175/106143012X13407275695634

Reviews recent research on measurements of major non-point source pollutants: nitrogen, phosphorus, mercury and zinc. The review also includes research on pollutant modeling, estimations, and management techniques. Reads more like an annotated bibliography than a literature review: connections aren't drawn between studies and overall trends in research aren't summarized.

Paul, M.J., Coffey, R., Stamp, J., and Johnson, T.. 2019. “ A Review of Water Quality Responses to Air Temperature and Precipitation Changes 1: Flow, Water Temperature, Saltwater Intrusion.” *Journal of the American Water Resources Association* 824– 843. <https://doi.org/10.1111/1752-1688.12710>.

This literature review covers peer reviewed and grey literature, post 2000, focused on air temperature and precipitation. Stream flow is a driver of changing water quality, and it

correlates with changes in precipitation. Studies predict increased stream flow in the northeast, which may correspond with increased pollutant fluxes. Water temperature is expected to increase in the northeast, and there is predicted to be less ice cover and earlier ice melt. All of these are attributed to warmer air temps, and could lead to earlier and longer stratification, changing algae blooms, pathogen survival rates, and organism functions. Predictions for saltwater intrusion were not noted for the north east, but for generally low-lying parts of the country it is more of a concern. The intrusion can affect habitat and drinking water.

Whitehead, P.G., R. L. Wilby, R. W. Battarbee, M. Kernana and A. J. Wade. (2009). A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal*, 54:1, 101-123

A review of climate change impacts on water quality, with a focus on impact in Europe. Changing water quality could happen via stream flows during extreme weather events. Drought flows could carry less diluted nutrients from streams into lakes. Longer growing seasons will also be drier, so flow regimes might need to be changed and the effects of those changes studied. The authors end with a call for integration across sectors to address degradation in water quality.

USEPA. 2009. National lakes assessment: A collaborative survey of the nation's lakes. EPA 841-R-09-001.

The Clean Water Act dictates the EPA report findings from information provided by states. Studies biological, recreational, and trophic conditions of lakes. Key findings include: 59% of lakes are in good biological condition, over a third have poor biological habitat, 20% of lakes have high phosphorus levels, the trophic state of over 75% lakes has been the same or improved. Lakes in the Northern Appalachian Region (which includes Maine) are typically in better shape than an average lake in the USA. Largest concern is on habitat. Too early to say overall lake quality is improving. Maine is one of three states not currently pursuing a state-level monitoring probability survey, which has been recommended by the EPA.

Human Behavior and Effects on Water Quality

Coleman, S., Hurley, S., Rizzo, D., Koliba, C., & Zia, A. (2018). From the household to watershed: A cross-scale analysis of residential intention to adopt green stormwater infrastructure.

Landscape and urban planning, 180, 195-206.

Green stormwater infrastructure (GSI) can provide stormwater management as well as other watershed benefits. Watersheds span across communities with varying demographics, be it neighborhood to neighborhood or town to town. What contextual factors may impact a homeowner to implement GSI practices? Homeowners across Vermont were surveyed on 6 GSI projects: diversion of roof runoff, infiltration trenches,

rain gardens, permeable pavers, tree box filters, green roofs, and constructed wetlands. After analyzing the data with logistic regression models, it was found that many homeowners see “no need” for many GSI projects. For five GSI projects, over half of respondents said they had “no need” for them. Town permitting requirements correlated with a change in response from “no need” to “not enough space,” “against property rules,” or “doesn’t look good.” Roof runoff diverter was the most commonly adopted or intended to adopt GSI. Note that many of the GSI projects studied overlap with LakeSmart’s BMPs.

Eisenhauer, B. W., Brehm, J. M., Stevenson, N., & Peterson J. (2016), Changing Homeowners’ Lawn Care Behavior to Reduce Nutrient Runoff, *Society & Natural Resources*, 29:3, 329-344

Rural development poses a threat to water quality, one land steward becomes many land stewards all with varying degrees of responsibility/knowledge, and NPS from Lawn Fertilization is a concern. Extension agencies performed various outreach campaigns (via newspaper articles, internet, tv programming, handouts & guides, workshops, etc.) on lawn care. A random sample of the community showed the educational outreach programs have a small but significant amount of changes in lawn care behavior. Noticeably over 75% of participants did not recall being exposed to extension education/outreach.

Griesinger, M, LH Palm-Forster, KD Messer, J Butler & J Fooks. (2017). Stewardship signaling and the power of using social pressures to reduce nonpoint source pollution. Selected Paper prepared for presentation at the 2017 Agricultural & Applied Economics Association Annual Meeting, Chicago, Illinois, July 30-August 1

A large number of water bodies are impaired (by USEPA), primarily from agricultural enterprises. Authors studied social pressures to implement green management practices in a model setting. Research participants were split up into groups and given choice on what practices to implement on their farm. The study also included different community interactions such as pressure from other farmers to “do the right thing”, from public outrage, and the ability to publicize one’s own good choices and stewardship. Data shows that ability to demonstrate their stewardship, rather receive than pressure from fellow farmers or the general public, could encourage farmers to engage in conservation efforts the most.

Junker, A. A. E., (2016). Assessing LakeSmart: The Development and Effectiveness of a Lake Protection Program. Honors Theses, Colby College. Paper 811.

<https://digitalcommons.colby.edu/honorstheses/811/>

This honors thesis looks at the development of LakeSmart and suggests improvements based on surveys and interviews with stakeholders. The first recommendation is to implement a mentoring process for those who do not meet LakeSmart standards. Other recommendations include continuing to foster relationships with lake association,

attending local events to increase outreach, and re-working the evaluator and screener training to include job shadowing.

Martin, D. M., & Johnson, F. A. (2019). Incorporating uncertainty and risk into decision making to reduce nitrogen inputs to impaired waters. *Journal of environmental management*, 249, 109380.

The effects of onsite wastewater treatment systems (OWTS) on water quality was studied in coastal north east in relationship to uncertainty and risk in decision making. Every decision a person makes comes with uncertainty and risk, which can be modeled and studied to determine what decisions people will or should make. Seven different advanced OWTS systems were studied using information about their costs, N removal rate, and other characteristics. The risk analyses, which varied levels of risk and cost of information, lead to different outcomes: no one OWTS was the best choice given that people have different information and different risk tolerances. Ultimately, Martin & Johnson state that more research needs to be done, but water quality researchers should incorporate uncertainty and risk into their future research.

Osherenko, Gail. (2014). Understanding the Failure to Reduce Phosphorus Loading in Lake Champlain: Lessons for Governance. *Vermont Journal of Environmental Law*. 15. 323. 10.2307/vermjenvilaw.15.2.323.

There is little research on social and political drivers of toxic algae blooms. Through a literature study and targeted interviews, Osherenko found that funding, while significant, was not enough to reach water quality goals. Lake Champlain Basin Program brought agencies together for planning, but due to their science-based approach, a lot of funding went to research that didn't lead to visible impacts on the water quality of their lake. Now they're ensuring more money is going to on the groundwork. They have found that farms are a significant source of P for Lake Champlain, but farms are highly valued in the community which makes them hard to regulate. A crisis (Hurricane Irene) spurred more legislative action. Their new methods include "kitchen table" meetings with farmers, environmental agencies working more closely together, and bottom-up decisions.

Rissman, A. R. and Carpenter, S. R., (2015). Progress on Nonpoint Pollution: Barriers & Opportunities. *Daedalus, The Journal of the American Academy of Arts & Sciences*, 144 (3) Summer 2015 . Available at SSRN: <https://ssrn.com/abstract=2806527>

When it comes to NPS, research is slow, but changes are fast. This review covers key research, but also discusses limitations of making data generally applicable because there are so many factors influencing water quality and NPS. Agreeing upon values and goals is key, and social science research can provide guidance when drafting regulation changing behavior.

Nonpoint Source Mitigation Strategies

McCrackin, M.L., Jones, H.P., Jones, P.C. and Moreno-Mateos, D. (2017). Recovery of lakes and coastal marine ecosystems from eutrophication: A global meta-analysis. *Limnology & Oceanography*, 62: 507-518.

A meta-analysis of 89 studies aimed at comparing the results of nutrient management studies to undisturbed conditions. The analysis showed that partial nutrient reductions can lead to full recovery, but the recovery timeline can be long. But recovery results are dependent on what the response variables are: some response variables indicated that improvement might not be possible at all.

Osgood, R. A. (2017). Inadequacy of best management practices for restoring eutrophic lakes in the United States: guidance for policy and practice. *Inland Waters*, 7(4):401-407.

A review of the literature indicates a small amount of studies actually show Best Management Practices (BMPs) reliably improve p-impaired lakes. Additionally, studies measuring long-term performance of BMPs are limited. Watershed management groups need to consider internal loading and treatments for that (e.g. alum) which are often cheaper (in terms of kg of P removed) and quicker. Authors cite that 80% P reduction is necessary to improve p-impaired lakes, but a 50% reduction is the best BMPs have been shown to accomplish, and a 25% reduction is more likely. The review does not cite anything about habitat protection, which may be a secondary benefit of BMPs.

Woodbury, J., & Shoemaker, C. A. (2012). Stochastic assessment of long-term impacts of phosphorus management options on sustainability with and without climate change. *Journal of Water Resources Planning and Management*, 139(5), 512-519.

Best Management Practices (BMPs) and Climate Change are both site-specific, so homeowners need to consider both to make effective conservation decisions. Soil and Water Assessment Tool models were used with historical and future weather events to determine the effectiveness of different agricultural BMPs. Woodbury & Shoemaker then compared both to determine how to best decrease phosphorus loading in a New York reservoir. There were statistical differences in the P removal of each management scenario. The only method that eliminated the trend towards increasing P was to eliminate P application throughout the watershed.

Structures and Septic Systems

Lusk, M.G., Toor, G. S., Yang, Y., Mechtensimer, S., De, M., & Obreza, T. A. (2017). A review of the fate and transport of nitrogen, phosphorus, pathogens, and trace organic chemicals in septic systems. *Critical Reviews in Environmental Science and Technology*, 47:7, 455-541

A comprehensive review of septic systems in regards to nitrogen, phosphorus, pathogens, and trace organic chemicals. Studies cited have shown that septic systems produce less nitrogen than fertilizer but are still a potential source of nitrogen in watersheds. In addition, lawns or vegetation overtop septic fields can absorb the nitrogen, but septic systems typically create more nitrogen than plants can take. One study states that septic systems contribute 4-55% of the total phosphorus load to lakes (Lombardo,

2006). But other studies claim that soil retention of phosphorus is generally efficient, and enhanced septic technologies have gotten phosphorus removal upwards of 90%.

Withers, P.J., Jordan, P., May, L., Jarvie, H.P. and Deal, N.E. (2014). Do septic tank systems pose a hidden threat to water quality? *Frontiers in Ecology and the Environment*, 12: 123-130.

Out of sight, out of mind. When designed, installed, and used properly, septic systems (STS) are very effective at removing nutrients from effluent. But they are often not optimal. For example, one third of soils in the USA do not meet drainfield requirements. Nonetheless, there is a low failure rate in US according to studies, and STSs are largely considered to produce a fraction of nutrient loading. However, nutrients are typically leaked at a low quantity but over a long period of time.

Driveways

Gilbert, J. K., & Clausen, J. C. (2006). Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. *Water research*, 40(4), 826-832.

Researchers believe driveways are one possible location to mitigate NPS. Previous studies had shown a significant amount of runoff comes from driveways compared to the amount of area they take up, but nothing had compared different types of driveways. Gilbert & Clausen compared the infiltration potential of replicated asphalt, permeable paver, and crushed-stone driveways in CT by measuring rainfall and runoff. Water runoff was reduced the most by crushed stone, then pavers, and lastly asphalt (which did not reduce runoff at all). Interestingly, paver driveways had less pollutants in their runoff than crushed stone. Runoff from crushed stone similar to runoff from asphalt except had lower phosphorus levels.

Lawns and Buffers

Flanagan, S. E.; Patrick, D. A.; Leonard, D. J.; and Stacey, P., (2017). Buffer Options for the Bay: Exploring the Trends, the Science, and the Options of Buffer Management in the Great Bay Watershed Key Findings from Available Literature. *PREP Reports & Publications*, 380.

This review of buffer research relevant for a New England coastal watershed found that most research involves defining the size buffer needed to maintain a watershed's natural ecosystem. There is very little research on the benefits of smaller buffers, which are more realistic in developed settings.

Gordon, Brad; Lenhart, Chris; Lewandowski, Ann; Wyatt, Gary; Current, Dean. (2016). Riparian Buffer Science: Status and Research Needs. Retrieved from the University of Minnesota Digital Conservancy, <http://hdl.handle.net/11299/182550>.

Minnesota has been seeing water quality decline, leading them to implement and encourage the implementation of BMPs. Here, the authors review why riparian buffers

are one of the BMPs implemented: they slow water and the plants uptake nutrients. Research shows that effectiveness varies according to “soil type, tillage practice, watershed size, geology, vegetation, and climate.” Research also shows that buffers can become saturated with nutrients, making them less effective. This review is agriculturally focused, because agricultural land can be a leading source of pollutants.

Koch, B. J., Febria, C. M., Gevrey, M., Wainger, L. A., & Palmer, M. A. (2014). Nitrogen removal by stormwater management structures: A data synthesis. *Journal of the American Water Resources Association*, 50(6), 1594-1607.

A study of larger Best Management Practices (BMPs): retention ponds, constructed wetlands, and vegetated swales. The authors reviewed the literature on the three BMPs to try and define each BMPs characteristics. In general, literature states that all three BMPs decline with age, in terms of ability to reduce the amount of nutrients entering a waterbody. The literature also indicates that BMP performance varies due to size, location, and maintenance schedule. The review ends with a call for more detailed research on each BMP.

Liu, Yaoze & Engel, Bernard & Flanagan, Dennis & Gitau, Margaret & McMillan, Sara & Chaubey, Indrajeet. (2017). A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. *Science of The Total Environment*, 601-602. 580-593.

Literature reviewed show measured efficiencies of Best Management Practices (BMPs) vary. Some studies showed BMP performance varies with seasons in addition to age. Multiple studies have shown that rain garden performance did not degrade with time, but did not mention the maintenance schedule (or lack thereof) used to maintain them. Other studies cite that BMPs don't reach long term water quality management goals as quickly as expected for many reasons. One study demonstrated how BMPs can in fact be sources, rather than mitigators, of pollutants. After reviewing the literature, there is a lack of empirical experimental and field data on BMPs. The authors suggests a list of specific data that needs to be recorded in the future to reduce inconsistencies between studies of BMPs.

Merrel, K., Howe, E., & Warren, S. (2009). Examining Shorelines, Littorally: The Effects of Unbuffered Lakeshore Development on Littoral Habitat. Retrieved 10 25, 2019, from Vermont Department of Environmental Conservation

Merrel et al. surveyed vermont lakes and ponds to study the shoreline's littoral zone (the area where light penetrates). They surveyed both unbuffered development and “natural” reference sites. There was 200% less shoreline tree cover, defined as the vegetation buffer 10m along the shore, in developed areas. They determined the developed sites provided much less habitat for wildlife: 90% less woody structure, less visual shading from predators, 124% less fine woody structure which serves as a cover for

macroinvertebrates, altered sediment structure (57% more sand), and more. Conversion of naturally treed shorelines to lawn causes a radical change in the litoral biotope.

Richardson, J. S., Naiman, R. J. & Bisson, P. A. (2012). How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices?, *Freshwater Science*, 31(1), 232–238, doi:10.1899/11-031.1.

A history of buffers; this review explains the fixed width buffer was adopted for its ease to monitor. Any protection is better than none at all. A width of 30m became the researched-based standard in the late 70s. Focus on streams in text and in historical research and legislation due to the commercial use of streams. Most recent studies show that a buffer needs to be much more than 30m wide to provide the desired functions of preserving wildlife habitat and maintaining water dynamics.