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Utilization of Emerging Data Science Technologies to Electric Power Sector Environmental, Health, and Safety Risks

Annotated Bibliography from a Literature Review

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Technical Update, December 2019

EPRI Project Manager

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ABSTRACT

This project investigates the research question: “What is the current state of utilization of emerging technologies for data collection, data science, and communication/visualization focused on environmental, health, and safety issues in the electric power industry?” This project, ‘Utilization of Emerging Data Science Technologies to Address Electric Power Sector Environmental, Health, and Safety Risks,’ is investigating the research question above in multiple stages. The approach taken in this report is to conduct a focused literature review. Data science search terms were combined with terms representative of the issues of focus of EPRI’s Environmental, Health, and Safety (EH&S) research program areas. The following eight research program areas were reviewed: Coal Combustion Product Management (P49); Transmission & Distribution: Environmental Issues (P51); Fish Protection (P54); Ecosystem Risk and Resiliency: Wildfire & Extreme Events (P55); Endangered and Protected Species (P195); Water Quality (P196), Energy, Environmental, and Climate Policy Analysis (P201); and Air Quality and Multimedia Characterization, Assessment and Health (P203). A subsequent technical update will cover the results of the same literature review approach applied to the remaining six EH&S research areas.

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PRIMARY AUDIENCE: EPRI staff; EPRI utility member companies' environmental, health and safety employees.

SECONDARY AUDIENCE: EPRI utility member companies' data science teams; external researchers, government researchers and compliance staff, and data science service providers interested in application of emerging technology to environmental, health and safety (EH&S) issues in the electric power industry.

KEY RESEARCH QUESTION

What is the current state &/or 'frontier' of utilization of emerging technologies for data collection, data science, and communication/visualization focused on EH&S issues in the electric power industry, as evidenced in the literature?

RESEARCH OVERVIEW

Note: For the purposes of this report the term data science refers to analysis that taps into multiple fields: statistics, the field of computer science, and domain knowledge (e.g., air quality science). For further background on the topic of data science, see EPRI report 3002013696 "Data Analytics: Overview and Natural Resource Applications Relevant to the Electric Power Industry."

A focused literature review was conducted to ascertain the current state or 'frontier' of utilization of emerging technologies and data science techniques on EH&S issues relevant to the electric power industry. Data science search terms (noted below) were combined with terms representative of the issues of focus of EPRI's EH&S research program areas.

Data science terms searched: neural network, algorithm, artificial intelligence (AI), remote sensing, machine learning (ML), big data

In this first of two technical updates, the following eight research program areas were reviewed: Coal Combustion Product Management (P49); Transmission & Distribution: Environmental Issues (P51); Fish Protection (P54); Ecosystem Risk and Resiliency: Wildfire & Extreme Events (P55); Endangered and Protected Species (P195); Water Quality (P196), Energy, Environmental, and Climate Policy Analysis (P201); and Air Quality and Multimedia Characterization, Assessment and Health (P203). The program area search terms were confirmed with EPRI program managers and are noted in each program's section in this report. After some trial-and-error testing, the final set of data science terms was chosen to cast a wide net for papers utilizing data science methods and emerging technology. For some areas (indicated in the report), additional terms for emerging data types or data science methods were included (e.g., hyperspectral imagery, sensors). The search was confined to English-language peer-reviewed papers and conference proceedings (and in rare cases, book chapters) published from 2004-2019.

For each of the 8 program areas covered in this report, the top 100-400 search return titles &/or abstracts were scanned and a sample of between 10-40 of these were reviewed more closely (e.g., reading the abstract and scanning full text articles when available). When considering articles for inclusion, we considered the following screening questions:

- Does it use an emerging technology for data collection?
- Does it use "big data" (high volume, high velocity, or high variety data)?
- Does it apply techniques from the field of computer science or other advanced analytical solutions to data analysis, aggregation, cleansing, or visualization?

From this, a high-level synthesis of findings was summarized by program, the search terms used were indicated, and a small sample (4-8 papers) was chosen to be highlighted in the annotated bibliography as indicative of themes of application of emerging technology for data collection or data science in the research area or a novel/interesting data science application.

The annotated bibliography contains standard reference information (e.g., citation and abstract), along with an indication of:

- The data science element of the paper (or in some cases, the emerging data collection or visualization technology used),
- The environmental area of relevance to the paper,
- Value criteria of the data science approach (e.g., time or cost savings, new insights, etc.), and
- Datasets used (if relevant).

KEY FINDINGS

This section provides a synthesis of key findings extracted from the results of the literature review regarding the current state or 'frontier' of utilization of emerging technologies and data science techniques on EH&S issues relevant to the electric power industry. It is important to note that these key findings represent conclusions drawn from the literature obtained through the specific methodology outlined above, and as such do not necessarily represent the complete status of emerging technology and data science in the electric power industry as a whole. Accordingly, key findings of the literature compiled through this review are as follows:

- ***While emerging technologies and data science methods are developing at a rapid pace, current uptake of these technologies in the environmental work of the electric power sector may be lagging behind what is possible.*** For example, Blair et al. (2019) stated "to date, there has been little work on data science applied to the understanding and management of the natural environment" and Budka et al. (2010) note that "environmental scientists often try to apply various machine learning techniques to their data without much success, mostly because of the lack of experience with different methods and required 'under the hood' knowledge." Li et al. (2019) provide a very insightful literature review of the use of big data in energy economy modeling, an area of relevance to EPRI's Program 201, and noted: "there is clear evidence therefore, that big data platforms and concepts have already begun to be applied in various sub-domains of the energy system [e.g., energy efficient computing, energy performance of buildings, and big data in the context of 'smart' cities and urban energy planning]. However, our 200+ paper review finds that the application of modern data science specifically to energy economy modelling and the implications for strategic decision making on energy and climate mitigation policy remain entirely unexplored."
- ***Despite these noted limitations, the literature review uncovered numerous applications of data science to environmental issues.*** Specifically, the searches employed and detailed below returned roughly 500 relevant papers that discuss the application of data science to issues relevant to the

electric power sector. Novel approaches to data science uncovered by the literature review include interesting examples such as the use of machine learning on environmental DNA (eDNA) metabarcoding data in a predictive model for benthic monitoring which Cordier et al. (2017) argue "could overcome and even bypass the cost and time-demanding [standard] morpho-taxonomic approaches in future biomonitoring" (applicable to P54), and another project (applicable to P195) called ARBIMON (Automated Remote Biodiversity Monitoring Network) that includes hardware and software for species identification from audio data.

- ***The literature review identified a number of large datasets (some of which can be classified as 'big data') relevant to EPRI's EH&S program areas.*** This is important because data science is often catalyzed by these large datasets. The table below provides an overview of the types of datasets identified and the EPRI program area to which they are most relevant. As shown, three datasets were identified that are relevant to P49 (Coal Combustion Product Management); one for P51 (T&D: Environmental Issues); one for P54 (Fish Protection); one for P55 (Ecosystem Risk and Resilience); two for P195 (Endangered and Protected Species); and one for P196 (Water Quality); and one for P201 (Energy, Environmental, and Climate Policy Analysis).

Table 1
Datasets identified in the literature review

Dataset	Source	EPRI Program Area
LANDSAT TM to estimate P and Cu concentrations in soil surface	Sridhar and Vincent, 2009	P49 – Coal Combustion Product Management
653 data points of coal properties (moisture content, ash content, lower heating value) from one year of operating data from one plant	Bekat et al., 2011	P49 – Coal Combustion Product Management
UAV derived video imagery	Messinger and Silman, 2016	P49 – Coal Combustion Product Management
High resolution multispectral satellite images along pipeline ROWs (Azerbaijan)	Bayramov, 2013	P51 – Transmission & Distribution: Environmental Issues
300 hydropower relicense mitigation requirements	DeRolph et al. 2016	P54 – Fish Protection
Hyperspectral data (1,336 spectra data points) of wetland species	Zomer et al., 2009	P55 – Ecosystem Risk and Resiliency: Wildfire & Extreme Events
ARBIMON (Automated Remote Biodiversity Monitoring Network) - over 3 million species audio recordings usable for ML classification	Kwok, 2019	P195 – Endangered and Protected Species
Species occurrence data from eBird	Sullivan et al. 2017	P195 – Endangered and Protected Species
Landsat, MERIS, Landsat 8, Sentinel-2, and MODIS satellite imagery to monitor water quality parameters including a specific chlorophyll-a data layer	Olmanson et al. 2015, and Bierman et al. 2011	P196 – Water Quality
Building Performance Database – for 1 million US homes	Chang and Han 2019	P201 – Energy, Environmental, and Climate Policy Analysis

- ***Artificial intelligence (AI) was a leading technology in the literature review, used to develop models for identification, classification, and prediction of environmental variables relevant to a number of EPRI EH&S program areas.*** AI is often used in concert with big data obtained from emerging hardware, such as unmanned aircraft systems (UASs), acoustic cameras and sonar, and satellites. For example, AI has been used to identify the components of coal and fly ash (P49); identify vegetation encroachment in ROWs using UASs (P51); identify and/or classify fish and fish behavior using video, acoustic camera/sonar or acoustic telemetry data (P54); improve prediction models and real-time disaster management for severe weather and natural disasters (P55); identify and classify wetlands (P55); model energy and water use in urban areas (P55); automatically identify species from imagery or acoustic data (P195); and estimate water quality parameters from satellite-based ocean color reflectance data (P196).
- ***In addition to applications of AI in the EH&S space, the literature review identified other novel emerging technologies.*** For example, the results included structure-from-motion analysis of drone-collected video imagery of an ash spill and laser-induced breakdown spectroscopy to identify coal ash components (P49); the Whooshh fish passage technology,[1] which includes the use of video and machine vision to identify fish and 'sensor fish' that can be released into hydropower units and record data to predict fish injury/mortality (P54); and lab-based reflectance spectroscopy for heavy metal identification and low cost water pollution sensors (P196). Other examples specific to air pollution include plane-mounted and stationary spectroscopy for measuring air pollutants; microscopy and ML to quantify particulate matter (P203), and 'flame radical imaging' used with ANN to predict NOx in flue gas (P49).
- ***The literature review suggests that standards around data transparency and sharing are on the horizon.*** A number of papers called for data transparency and sharing around key research areas. For example, Allen et al. (2018) proposed an idea of developing a 'knowledge discovery framework' central space to aggregate energy-water nexus data and tools for analysis. Hampton et al. (2013) offered the following on data sharing: "simply put, the era of data-intensive science is here. Those who step up to address major environmental challenges will leverage their expertise by leveraging their data. Those who do not run the risk of becoming scientifically irrelevant." Blair et al. (2019) included data sharing as part of a broad research roadmap to better incorporate data science in ecological research. Burton et al. (2015) call for transparency in camera trap data-based research. Liu et al. (2007) call for more integrated, interoperable air quality data: "…a set of intelligent, robust algorithms and models for environmental modelling," and user interfaces to tap into the data and applications.
- ***While exploring a wide variety of emerging technologies and data science methods, the literature review identified regulatory barriers to the use of these technologies and methods for compliance purposes.*** New and emerging technologies and data science methods challenge established ways of conducting environmental monitoring and measurement. Regulatory barriers exist for the use of these technologies for regulatory compliance requirements due to a variety of factors, including lack of training and knowledge of emerging methods on the part of regulators and data validity, precision and accuracy issues (whether real or perceived). For example, Shaeffer et al. (2013) surveyed staff perceptions of satellite data at EPA and found that none of the staff surveyed had personally used satellite data, but that half indicated they knew a colleague that was doing so. EPA

[1] Note that EPRI is currently testing the Whooshh technology at a hydropower facility in Maine, focusing on alewife and blueback herring.

staff also held perceptions that data science came with a high price tag (Shaeffer et al., 2013). Hoff and Christopher (2009) note that satellite data would not be appropriate for compliance purposes because "…the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring (aerosol optical depth) AOD is +/-20%, and the relationship to PM2.5 is at best +/-30% in controlled measurements in which overlying aerosols, aerosol type, and boundary layer structure are known. This is not currently sufficient for regulatory use." Researchers are working to address these challenges: for example, Despini and Teggi (2013) used a new algorithm (Sharpening Water Thermal Imagery) to improve resolution of thermal and reflectivity satellite data for monitoring the thermal profile of coastal areas in Italy for compliance purposes. Messinger et al (2016) provide the example of a 3rd party watchdog to provide an independent assessment of ash pond spill volume using drone-collected video and structure-from-motion imagery analysis. Results from the literature review suggest that these types of barriers and challenges will need to be addressed moving forward in order to mainstream emerging technologies and data science into the regulatory compliance work of industry sectors such as electric power.

WHY THIS MATTERS

Over the last decade, there has been a growth of business publications and research related to big data, data analytics, and data science stemming from the general increase in the volume, variety and velocity of data along with increased computing capabilities. Sources of big data have also grown with the emergence of new &/or lower cost platforms for collecting big data such as satellite data from traditional and cube satellites; aerial, aquatic and terrestrial drones; citizen science apps such as eBird and iNaturalist; and a variety of sensors. Over the last five years, EPRI and the electric power industry have been analyzing opportunities related to data coming from advanced metering infrastructure, grid sensors, customer data, video monitoring data, and sensor and other data from power plant equipment. To date, however, there has not been a focus on opportunities for data science focused on environmental, health and safety (EH&S) issues in the electric power industry. This literature review is one steps towards bridging that gap. When early results were reviewed with program managers, many noted value in this review to ensure that EPRI research was keeping up with and utilizing promising datasets and data science methods identified in the reviews.

HOW TO APPLY RESULTS

EPRI staff and electric power; other industry environmental, health, and safety managers and staff; external researchers, service providers, and government staff can quickly review evidence from the literature on the current state or 'frontier' of utilization of emerging technologies on EH&S issues relevant to electric power industry. Research and pilot test applications could be proposed to apply the approaches found in the literature.

LEARNING AND ENGAGEMENT OPPORTUNITIES

There are multiple resources to learn more and apply data science to environmental, health and safety issues relevant to the electric power industry:

- Pilot test applications with electric power companies could be developed in collaboration with EPRI. EPRI contact: Becca Madsen, Senior Technical Leader, bmadsen@epri.com, 940.231.4359.
- "Utilization of Emerging Data Science Technologies to Electric Power Sector Environmental, Health, and Safety Risks: Early Insights from Interviews" (3002016583, 2019).
- Other resources that will be compiled as part of this and a broader research effort, including:
- Important datasets
- Examples of visualization/communication
- Use cases
- P55 report 3002013696 "Data Analytics: Overview and Natural Resource Applications Relevant to the Electric Power Industry."
- EPRI's Technology Innovation program has sponsored a great deal of research on the application of data analytics to other aspects of the electric power industry (e.g., beyond the environment, health and safety focus of this report). See summaries of 17 EPRI reports in Table 2 of the above-mentioned P55 report 3002013696.

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PROGRAM: Energy and Environment Core Project / Technology Innovation

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ACRONYMS AND ABBREVIATIONS

AI	artificial intelligence
ANN	artificial neural network
CCP	coal ash combustion products
CNN	convolutional neural networks
EH&S	environmental, health and safety
GIS	geographic information systems
GW	guided wave
KNN	K nearest neighbor
LIDAR	light detection and ranging
ML	machine learning
MLR	multiple linear regression
NN	neural network
PCA	principal component analysis
ROW	right of way
SAR	synthetic-aperture radar
UAS	unmanned aircraft systems
UAV	unmanned aerial vehicle
VSF	vertical slot fishways
WNN	wavelet neural network

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION TO THE ANNOTATED BIBLIOGRAPHY

For an introduction to the overall research question, approach, and overall findings, see the Executive Summary. The eight EPRI EH&S research program areas covered in this technical brief are: Coal Combustion Product Management (P49), Transmission & Distribution: Environmental Issues (P51), Fish Protection (P54), Ecosystem Risk and Resiliency: Wildfire & Extreme Events (P55), Endangered and Protected Species (P195), Water Quality (P196), Energy, Environmental, and Climate Policy Analysis (P201); and Air Quality and Multimedia Characterization, Assessment and Health (P203).

The programs are listed below numerically by program number. Each research area section includes a brief overall commentary on the literature review findings, the search strings for the program and 4-8 highlighted articles.

2
P49 – COAL COMBUSTION PRODUCT MANAGEMENT

Overall Commentary on the Literature Review Findings

The first search string implemented by the analysis (and detailed below) returned many results focused on the process of flue gas desulphurization (FGD) as opposed to the residuals of FGD. For example, many articles incorporated neural networks for better simulation or prediction of FGD efficiency. The first search string also returned many applications of AI or machine learning to groundwater modeling—some for specific contaminants (e.g., arsenic, fluoride, nitrate), and some focused on developing countries (e.g., Bangladesh, Iran, Southeast Asia). A potentially helpful search result was a book chapter entitled "Review of Application of Artificial Neural Networks in Ground Water Modeling" (Kumari et al., 2015).

Two additional search strings were used to attempt to identify data science applications more specifically to coal combustion products (CCP) or coal combustion residuals (CCR). Within the search returns selected for inclusion in this review, four articles used remote sensing for ash discharge detection, and while the spatial analytical tools (e.g., GIS) and use of satellite imagery in the articles are not new, we include these examples due to the novel application to the environmental issue. Two articles were related to a 2000 ash pond breach to the Brahmani river in the state of Odisha, India (Rout et al., 2005; Gupta et al., 2005); one (Alkan 2009) looked at turbidity from a Turkish power plant discharging into the Black Sea from remote sensing imagery; and one (Sridhar and Vincent 2009) estimated phosphorous and copper concentrations of the Tennessee Valley Authority ash pond breach in 2008 using Landsat imagery.

A number of papers selected for inclusion utilized data science methods to determine the components of coal and fly ash. Wei et al. (2016) quantified and later predicted the components of coal ash using a laser-induced breakdown spectroscopy technique, wavelet neural network (WNN), and ANN. Zhang et al. (2017) used an almost identical technique as the former article but used a principal component analysis (PCA) along with a WNN model. Das and Sabat (2008) similarly predict chemical composition of fly ash but using three types of ANNs. Bekat et al. (2012) took one year of data from one power plant (653 data points on coal moisture content, ash contents, lower heating value; and plant operating data), and used ANN to predict the ratio of bottom ash to coal burned. Douma et al. (2017) used ANN to predict concrete characteristics (slump flow, L-box ratio, V-funnel time, compressive strength at 28 days) of concrete containing fly ash. Finally, Bagheri et al. (2017) used fuzzy logic and ANN to model and predict landfill leachate of 14 contaminants, of which molybdenum, sodium and chemical oxygen demand were more important.

Table 2-1
Search strings for program 49

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "artificial intelligence" OR “remote sensing” OR “machine learning” OR “big data”)	AND (“coal combustion products” OR “groundwater contamination” OR "ash ponds" OR "flue gas desulfurization")	7,730	100	23
	AND (“coal combustion reuse” or “coal combustion waste” OR “coal combustion components”)	0	NA	NA
	AND (“coal ash” OR “coal combustion residuals” OR “fly ash” OR “bottom ash” OR “boiler slag” -concrete)*	7,700	100	15
Total				**38**
Articles highlighted				**6**

*Initial search results were picking up too many irrelevant terms related to concrete, so the term was removed in this search string.

Highlighted Literature

Article Title	A Review of Application of Artificial Neural Network in Ground Water Modeling (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of artificial neural networks to predict groundwater table and quality
Subject Area	Groundwater quality
Program Area	P49
Abstract	“Artificial Neural Networks (ANNs) are modelling tools having the ability to adapt to and learn complex topologies of inter-correlated multidimensional data. ANNs are inspired by biological neuron processing, have been widely used in different fields of science and technology incorporating time series forecasting, pattern recognition and process control. ANN has been successfully used for forecasting of groundwater table and quality parameters like nitrate, total dissolved solids. In case of groundwater quality prediction, availability of good quality data of better precision is required. ANNs are classified as Feed-forward neural networks (FFNNs), Recurrent neural networks (RNNs), Elman Backpropagation Neural Networks, Input Delay feed-forward Backpropagation Neural Network, Hopfield Network. The artificial neural networks’ (ANNs) ability to extract significant information provides valuable frameworks for the representation of relationships present in the structure of the data. The evaluation of the output error after the retraining of an ANN shows us that this procedure can substantially improve the achieved results. Through this review work it is observed that in most hydrological modeling cases FFNN and LM algorithm performed well till today's published research work.”
Value Criteria	Provide important new insights (improved modeling accuracy)
Dataset	NA

Citation	Kumari, Neeta, Gopal Pathak, and Om Prakash. "A Review of Application of Artificial Neural Network in Ground Water Modeling." In Recent Advances in Mathematics, Statistics and Computer Science, 393–402. WORLD SCIENTIFIC, 2015. https://doi.org/10.1142/9789814704830_0036.
Additional Information	This is a book chapter ($40 for online access).

Article Title	Application of Artificial Intelligence for the Management of Landfill Leachate Penetration into Groundwater, and Assessment of Its Environmental Impacts (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of fuzzy logic and neural networks in landfill leachate simulation
Subject Area	Groundwater quality
Program Area	P49
Abstract	"The current research was an effort to simulate landfill leachate penetration into groundwater using fuzzy logic and neural network modeling approaches. The obtained models were used as efficient tools for predicting leachate penetration and assessment of its environmental impacts. The training procedures were successful for both neural networks and fuzzy models. The train and test models showed over 70 perfect matches between the observed and the simulated values. The coefficient of determination for train model by fuzzy logic was 0.99998, which was even more precise than neural networks. The introduced intelligent models were useful for examining environmental impacts of contaminants because they could simulate the concentration of contaminants with high accuracy. These models could discern the relation between concentration of leachate at a given depth and concentration of leachate in groundwater. The analysis of 14 input variables in the modeling process indicated almost the same results for both modeling approaches. The analysis of contaminants showed that the Molybdenum, Sodium and Chemical Oxygen Demand are the three most important variables in the simulation of leachate penetration into groundwater for the study area. It was observed that heavy metals should be monitored carefully when leachate penetrates into groundwater."
Value Criteria	Provide important new insights (improved modeling/simulation accuracy)
Dataset	NA
Citation	Bagheri, Majid, Alireza Bazvand, and Majid Ehteshami. "Application of Artificial Intelligence for the Management of Landfill Leachate Penetration into Groundwater, and Assessment of Its Environmental Impacts." Journal of Cleaner Production 149 (April 15, 2017): 784–96. https://doi.org/10.1016/j.jclepro.2017.02.157.
Additional Information	NA

Article Title	Classification and Discrimination of Coal Ash by Laser-Induced Breakdown Spectroscopy (LIBS) Coupled with Advanced Chemometric Methods (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of emerging technology (laser-induced spectroscopy) and AI (wavelet neural network) to classify and identify coal ash component
Subject Area	CCP

Program Area	P49
Abstract	"The classification and identification of coal ash contributes to recycling and reuse of metallurgical waste. This work explores the combination of the laser-induced breakdown spectroscopy (LIBS) technique and independent component analysis-wavelet neural network (ICA-WNN) for the classification analysis of coal ash. A series of coal ash samples were compressed into pellets and prepared for LIBS measurements. At first, principal component analysis (PCA) was used to identify and remove abnormal spectra in order to optimize the training set for the WNN model. And then, ICA was employed to select and optimize input variables for the WNN model. The classification of coal ash was carried out by using the WNN model with optimized model parameters (the number of hidden neurons (NHN), the number of iterations (NI), the learning rate (LR) and the momentum) and input variables optimized by ICA. Under the optimized WNN model parameters, the coal ash samples for test sets were identified and classified by using WNN and artificial neural network (ANN) models, and the WNN model shows a better classification performance. It was confirmed that the LIBS technique coupled with the WNN method is a promising approach to achieve the online analysis and process control of the coal industry."
Value Criteria	Provide important new insights (improved modeling accuracy)
Dataset	NA
Citation	Zhang, Tianlong, Chunhua Yan, Juan Qi, Hongsheng Tang, and Hua Li. "Classification and Discrimination of Coal Ash by Laser-Induced Breakdown Spectroscopy (LIBS) Coupled with Advanced Chemometric Methods." Journal of Analytical Atomic Spectrometry 32, no. 10 (October 4, 2017): 1960–65. https://doi.org/10.1039/C7JA00218A.
Additional Information	NA

Article Title	Mapping and Estimation of Phosphorus and Copper Concentrations in Fly Ash Spill Area Using LANDSAT TM Images (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of remote sensing (LANDSAT imagery) and mapping algorithms to estimate P and Cu concentrations in soil surface from fly ash spill
Subject Area	Ash spill
Program Area	P49
Abstract	"In summary, the application of P and Cu mapping algorithms from LANDSAT TM images have allowed us to map and estimate the increase in surface concentrations of these two elements as a result of fly ash spill. These results show the effective use of multispectral satellite image analysis in determining surface soil chemical concentrations. Compared to point measurements made by ground-based soil sampling and chemical analysis, the satellite-based measurements have a great advantage in mapping the spatial distribution and concentration of elements and chemical compositions over time. As LANDSAT TM has 30-m spatial resolution, there is a measurement by the satellite for every 1/5 of an acre (the area covered by one pixel) during each overpass, which would be cost prohibitive for point measurements that require manual soil sample collection and laboratory analysis of each sample. Satellite monitoring of surface soil elemental concentrations for environmental purposes can surpass point measurements on the ground and measured in the laboratory, at least for P and Cu."

Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time of field monitoring) Provide important new insights (provides opportunity of greater frequency of monitoring)
Dataset	LANDSAT TM images
Citation	Citation: Sridhar, B. B. M., and R. K. Vincent. "Mapping and Estimation of Phosphorus and Copper Concentrations in Fly Ash Spill Area Using LANDSAT TM Images." PE&RS, Photogrammetric Engineering & Remote Sensing 75, no. 9 (2009): 1031–33. https://www.asprs.org/wp-content/uploads/pers/2009journal/september/highlight.pdf.
Additional Information	Additional Information: This study used Landsat and mapping algorithms to map ash pond breach and P and Cu concentration from the 2008 Kingston Fossil Plant coal ash spill.

Article Title	Prediction of Properties of Self-Compacting Concrete Containing Fly Ash Using Artificial Neural Network (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of artificial neural networks to predict properties of concrete that includes fly ash
Subject Area	Chemical composition
Program Area	P49
Abstract	"This paper investigates the feasibility of using artificial neural networks (ANNs) modeling to predict the properties of self-compacting concrete (SCC) containing fly ash as cement replacement. For the purpose of constructing this model, a database of experimental data was gathered from the literature and used for training and testing the model. The data used in the artificial neural network model are arranged in a format of six input parameters that cover the total binder content, fly ash replacement percentage, water–binder ratio, fine aggregates, coarse aggregates and superplasticizer. Four outputs parameters are predicted based on the ANN technique as the slump flow, the L-box ratio, the V-funnel time and the compressive strength at 28 days of SCC. To demonstrate the utility of the proposed model and improve its performance, a comparison of the ANN-based prediction model with other researcher's experimental results was carried out, and a good agreement was found. A sensitivity analysis was also conducted using the trained and tested ANN model to investigate the effect of fly ash on SCC properties. This study shows that artificial neural network has strong potential as a feasible tool for predicting accurately the properties of SCC containing fly ash."
Value Criteria	Provide important new insights (improved model accuracy)
Dataset	"a database of experimental data gathered from the literature"
Citation	Belalia Douma, Omar, Bakhta Boukhatem, Mohamed Ghrici, and Arezki Tagnit-Hamou. "Prediction of Properties of Self-Compacting Concrete Containing Fly Ash Using Artificial Neural Network." Neural Computing and Applications 28, no. 1 (December 1, 2017): 707–18. https://doi.org/10.1007/s00521-016-2368-7.
Additional Information	NA

Article Title	Prediction of the Bottom Ash Formed in a Coal-Fired Power Plant Using Artificial Neural Networks (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of artificial neural networks to predict quantity of bottom ash
Subject Area	CCP
Program Area	P49, GEN
Abstract	"The amount of bottom ash formed in a pulverized coal-fired power plant was predicted by artificial neural network modeling using one-year operating data of the plant and the properties of the coals processed. The model output was defined as the ratio of amount of bottom ash produced to amount of coal burned (Bottom ash/Coal burned). The input parameters were the moisture contents, ash contents and lower heating values of the coals. The total 653 data were divided into two groups for the training (90% of the data) and the testing (10% of the data) of the network. A three-layer, feed-forward type network architecture with back-propagation learning was used in the modeling study. The activation function was sigmoid function. The best prediction performance was obtained for a one hidden layer network with 29 neurons. The learning rate and the tolerance value were 0.2 and 0.05, respectively. R2 (coefficient of determination) values between the actual (Bottom ash/Coal burned) ratios and the model predictions were 0.988 for the training set and 0.984 for the testing set. In addition, the sensitivity analysis indicated that the ash content of coals was the most effective parameter for the prediction of the ratio of bottom ash to coal burned."
Value Criteria	Provide important new insights (improved model accuracy)
Dataset	653 data points of properties of coal (moisture content, ash contents, lower heating value) from a year of operating data from one plant
Citation	Bekat, Tugce, Muharrem Erdogan, Fikret Inal, and Ayten Genc. "Prediction of the Bottom Ash Formed in a Coal-Fired Power Plant Using Artificial Neural Networks." Energy, The 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy, ECOS 2011, 45, no. 1 (September 1, 2012): 882–87. https://doi.org/10.1016/j.energy.2012.06.075.
Additional Information	NA

References

Alkan, Mehmet. "DETECTION OF COAL ASH TURBIDITY IN MARINE ENVIRONMENT USING REMOTE SENSING." *Fresenius Environmental Bulletin* 18 (January 1, 2009): 2072–78.

Bagheri, Majid, Alireza Bazvand, and Majid Ehteshami. "Application of Artificial Intelligence for the Management of Landfill Leachate Penetration into Groundwater, and Assessment of Its Environmental Impacts." *Journal of Cleaner Production* 149 (April 15, 2017): 784–96. https://doi.org/10.1016/j.jclepro.2017.02.157.

Bekat, Tugce, Muharrem Erdogan, Fikret Inal, and Ayten Genc. "Prediction of the Bottom Ash Formed in a Coal-Fired Power Plant Using Artificial Neural Networks." *Energy*, The 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy, ECOS 2011, 45, no. 1 (September 1, 2012): 882–87. https://doi.org/10.1016/j.energy.2012.06.075.

Belalia Douma, Omar, Bakhta Boukhatem, Mohamed Ghrici, and Arezki Tagnit-Hamou. "Prediction of Properties of Self-Compacting Concrete Containing Fly Ash Using Artificial Neural Network." *Neural Computing and Applications* 28, no. 1 (December 1, 2017): 707–18. https://doi.org/10.1007/s00521-016-2368-7.

Das, Sarat, and Akshaya Sabat. "Using Neural Networks for Prediction of Some Properties of Fly Ash." *Electronic Journal of Geotechnical Engineering* 13 (January 1, 2008). https://www.researchgate.net/publication/253981637_Using_Neural_Networks_for_Prediction_of_Some_Properties_of_Fly_Ash.

Gupta, P. K., and A. P. Singh. "Disaster Management for Nandira Watershed District Angul (Orissa) India, Using Temporal Remote Sensing Data and Gis." *Environmental Monitoring and Assessment* 104, no. 1 (May 1, 2005): 425–36. https://doi.org/10.1007/s10661-005-1678-5.

Kumari, Neeta, Gopal Pathak, and Om Prakash. "A Review of Application of Artificial Neural Network in Ground Water Modeling." In *Recent Advances in Mathematics, Statistics and Computer Science*, 393–402. WORLD SCIENTIFIC, 2015. https://doi.org/10.1142/9789814704830_0036.

Messinger, Max, and Miles Silman. "Unmanned Aerial Vehicles for the Assessment and Monitoring of Environmental Contamination: An Example from Coal Ash Spills." *Environmental Pollution* 218 (November 1, 2016): 889–94. https://doi.org/10.1016/j.envpol.2016.08.019.

Rout, D. K., P. K. Parida, and G. Behera. "Man-Made Disaster-a Case Study of Nalco Ash-Pond in The Angul District, Orissa Using Remote Sensing and GIS Technique." *Journal of the Indian Society of Remote Sensing* 33, no. 2 (June 1, 2005): 291–95. https://doi.org/10.1007/BF02990048.

Sridhar, B. B. M., and R. K. Vincent. "Mapping and Estimation of Phosphorus and Copper Concentrations in Fly Ash Spill Area Using LANDSAT TM Images." *PE&RS, Photogrammetric Engineering & Remote Sensing* 75, no. 9 (2009): 1031–33. https://www.asprs.org/wp-content/uploads/pers/2009journal/september/highlight.pdf.

Wei, Jiao, Juan Dong, Tianlong Zhang, Zhanmei Wang, and Hua Li. "Quantitative Analysis of the Major Components of Coal Ash Using Laser Induced Breakdown Spectroscopy Coupled with a Wavelet Neural Network (WNN)." *Analytical Methods* 8, no. 7 (February 11, 2016): 1674–80. https://doi.org/10.1039/C5AY02994E.

Zhang, Tianlong, Chunhua Yan, Juan Qi, Hongsheng Tang, and Hua Li. "Classification and Discrimination of Coal Ash by Laser-Induced Breakdown Spectroscopy (LIBS) Coupled with Advanced Chemometric Methods." *Journal of Analytical Atomic Spectrometry* 32, no. 10 (October 4, 2017): 1960–65. https://doi.org/10.1039/C7JA00218A.

3
P51 – TRANSMISSION & DISTRIBUTION: ENVIRONMENTAL ISSUES

Overall Commentary on the Literature Review Findings

The first search string implemented by the analysis (and detailed below) returned a set of articles which, although very relevant to research related to power delivery, generally did not include an environmental aspect relevant to P51 research. Some examples included the use of drones, satellite imagery, light detection and ranging (LIDAR), polarimetric synthetic-aperture radar (SAR) imagery, guided wave (GW) propagation, hyperspectral imagery, or video with some form of modelling or application of AI on rights of way (ROW) for:

- Automatic pole detection,
- Detection of encroachment (construction, vehicles, homes, and vandalism),
- Detection of erosion,
- Detection of trespassing,
- Maintenance inspections,
- Disaster response,
- Leak or spill detection (in oil pipelines),
- Wood pole health assessment, and
- Identification of risk from snow on lines.

Sources of examples above: Long et al., 2018; Marathe, 2019; Adewuyi, 2013; Yokoyama et al., 2011; Lukowski et al., 2004; Dackermann et al., 2014; Olawale et al., 2015; Hafeez et al., 2018; Olawale et al., 2015; Keskin et al., 2015; Zaman et al., 2019; Wamsley et al., 2018; Sharma et al., 2015; Cetin et al., 2009.

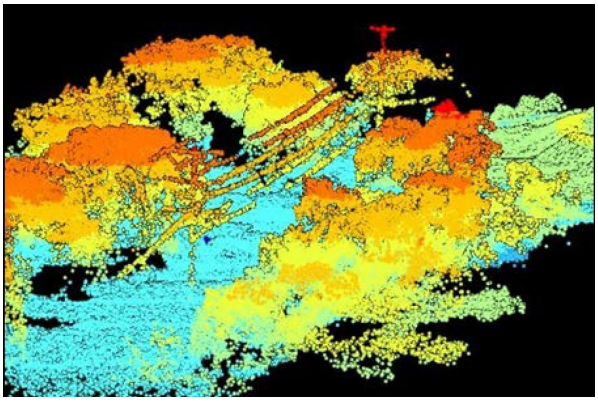

Figure 3-1
3D point cloud of transmission line and vegetation (EPRI report 3002010873, 2017)

A majority of the articles above focused on above- or below-ground oil pipeline rights of way. Two of the above articles also considered vegetation encroachment and used forms of AI such as a fuzzy logic model (Marathe, 2019; Hafeez et al., 2018). In addition, Ituen and Sohn (2010) compared "conventional methods of [ROW] maintenance with the remote sensing techniques using LIDAR and digital cameras" and found that these emerging technologies "can be faster, simpler, and save significantly in man-hours" for powerline inspection and maintenance in comparison to traditional methods. Jardini et al. (2018) described the early stages of developing 3D modeling and automatically detecting ROW vegetation encroachment from imagery collected via UAS in Brazil. In Indonesia, Janahiraman et al. (2017) used Google maps imagery along with a statistical method (gray level co-occurrence matrix, or GLCM) and ANN to identify vegetation classes and potentially dangerous trees.

Going beyond vegetation encroachment, Pajares (2015) provides a very good review article of the many applications of UAS, including species or habitat classification and monitoring, fire risk detection, and identification of invasive species. The article also discusses many technical aspects of the kinds of data collection technology that could be used with UAS. Bayramov (2013) used high-resolution multispectral satellite imagery for monitoring restoration requirements and detecting erosion along a very large pipeline ROW (10 million square miles) in Azerbaijan.

Finally, although not an application of emerging technology or data science, Dwyer et al. (2016) used wood pole location data and standard GIS analysis to estimate pole density in areas without available data to identify priority areas for avian mitigation requirements.

Although search strings included terms intended to pick up on environmental issues related to substations (see below) we found no articles relevant to the P51 research. The P196 literature review identified one article using LIDAR data collected from a UAS at a substation that was analyzed to identify minor oil pollution (Babichenko et al., 2004). If time allows for further investigation, we would recommend a focused search on substation environmental search terms.

Table 3-1
Search strings for program 51

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "artificial intelligence" OR “remote sensing” OR “machine learning” OR “big data”)	(“right of way” OR “integrated vegetation management” OR “electricity transmission poles” OR "utility pole")	7,390	100	26
("drone")	(“right of way” OR “integrated vegetation management” OR “electricity transmission poles” OR "utility pole")	1,080	60	9
("drone" OR "neural network" OR "artificial intelligence" OR “remote sensing” OR “machine learning” OR “big data”)	("avian protection" OR "PCB remediation" OR "substation runoff")	55	55	6
Articles identified in other program searches				1
Total				**42**
Articles highlighted				**4**

Highlighted Literature

Article Title	Optimization of Environmental Monitoring Principles along Oil and Gas Pipelines Using GIS and Remote Sensing (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Uses high resolution multispectral satellite imagery for very large-scale ROW mitigation monitoring
Subject Area	Land cover analysis
Program Area	P51
Abstract	“The main objectives of this research were to evaluate the vegetation restoration progress and to predict erosion-prone areas along the BTC Oil and the SCP Gas pipelines. Based on the GIS and Remote Sensing analysis of high resolution multispectral satellite images, the total area of restored vegetation cover between 2005 and 2007 was detected to be 10.7 million sq. m. An area of 8.9 million sq. m. of ground vegetation needed restoration. USLE performed better than MMF model by identifying of 192 erosion occurrences out of 316 along the pipelines.”
Value Criteria	Reduce costs (of monitoring large area) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA

Citation	Bayramov, E. "Optimization of Environmental Monitoring Principles along Oil and Gas Pipelines Using GIS and Remote Sensing." In *2013 7th International Conference on Application of Information and Communication Technologies*, 1–3, 2013. https://doi.org/10.1109/ICAICT.2013.6722681.
Additional Information	NA

Article Title	Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs) (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of UAS for data collection and applications relevant to ROW management
Subject Area	Multiple
Program Area	P51, P55, P195, P54
Abstract	"Remotely Piloted Aircraft (RPA) is presently in continuous development at a rapid pace. Unmanned Aerial Vehicles (UAVs) or more extensively Unmanned Aerial Systems (UAS) are platforms considered under the RPAs paradigm. Simultaneously, the development of sensors and instruments to be installed onboard such platforms is growing exponentially. These two factors together have led to the increasing use of these platforms and sensors for remote sensing applications with new potential. Thus, the overall goal of this paper is to provide a panoramic overview about the current status of remote sensing applications based on unmanned aerial platforms equipped with a set of specific sensors and instruments. First, some examples of typical platforms used in remote sensing are provided. Second, a description of sensors and technologies is explored which are onboard instruments specifically intended to capture data for remote sensing applications. Third, multi-UAVs in collaboration, coordination, and cooperation in remote sensing are considered. Finally, a collection of applications in several areas are proposed, where the combination of unmanned platforms and sensors, together with methods, algorithms, and procedures provide the overview in very different remote sensing applications. This paper presents an overview of different areas, each independent from the others, so that the reader does not need to read the full paper when a specific application is of interest."
Value Criteria	Reduce regulatory risk (meeting vegetation management requirements) Reduce costs (of monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA
Citation	Citation: Pajares, Gonzalo. "Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs)." *Photogrammetric Engineering & Remote Sensing* 81, no. 4 (April 1, 2015): 281–330. https://doi.org/10.14358/PERS.81.4.281.
Additional Information	Additional Information: This is a useful review article of many kinds of data/sensors that could be used on UAS, and the kinds of applications of this technology, including species or habitat classification/monitoring, fire, invasive species detection, and other applications

Article Title	Practical Experience of the Use of RGB Camera Images in UAV for the Generation of 3D Images in the Accurate Detection Distance of Vegetation Risk in Right-of-Way Transmission Line (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Development stage; use of 3D modeling to automatically detect ROW vegetation encroachment from imagery collected via UAS
Subject Area	Land cover analysis
Program Area	P51
Abstract	"The Brazilian National Interconnected System has an extensive power transmission grid, where the lines are mostly located far from the urban centers and in difficult access areas. This makes inspection and maintenance more expensive and complex. In this sense, it is important to monitor and apply technological innovations in terms of equipment (sensors, cameras), telecommunication systems and vehicles, which aim at reducing costs, reducing environmental impacts and increasing reliability. This work will investigate the use of 3D modeling of a training transmission line stretch using RGB images captured using sensor coupled in unmanned aerial vehicle. It is a first investigative step for the specific purpose of detecting, with high accuracy, the vegetation along the right-of-way. Exemplifications and conclusions are presented at the end of the paper."
Value Criteria	Reduce costs (of monitoring large area) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA
Citation	Jardini, Mauricio G. M., Augustinho José Menin Simões, José Antonio Jardini, Jose Mauricio Scovino de Souza, and Ferdinando Crispino. "Practical Experience of the Use of RGB Camera Images in UAV for the Generation of 3D Images in the Accurate Detection Distance of Vegetation Risk in Right-of-Way Transmission Line." In *Geo-Spatial Knowledge and Intelligence*, edited by Hanning Yuan, Jing Geng, Chuanlu Liu, Fuling Bian, and Tisinee Surapunt, 152–60. Communications in Computer and Information Science. Springer Singapore, 2018. https://link.springer.com/chapter/10.1007/978-981-13-0896-3_16.
Additional Information	NA

Article Title	The Way Forward: Advances in Maintaining Right-of-Way of Transmission Lines (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of LIDAR and imagery data for ROW inspection and maintenance
Subject Area	Land cover analysis
Program Area	P51
Abstract	"An up-to-date inventory and tracking system for the vegetation growing along the Right-of-Way is vital. Tree-related incidents account for a large portion of electric power failures. Most powerline monitoring is conducted manually which is very costly and time-consuming. Moreover, manual Right-of-Way inspection does not provide the timely answers that are possible in surveying using today's latest technology. However, LiDAR is fast becoming the dominant corridor mapping method-the primary source for anomaly detection-and images from digital cameras

	are being used to verify these anomalies. This paper compares conventional methods of Right-of-Way maintenance with the remote sensing techniques using LiDAR and digital cameras. It was found that powerline inspection and maintenance can be faster, simpler, and save significantly in man-hours when the powerline corridor is surveyed with the latter method. The technology also supports important maintenance decisions by helping to maintain legislated clearances between powerlines and physical objects or encroachments."
Value Criteria	Reduce regulatory risk (meeting vegetation management requirements) Reduce costs (of monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA
Citation	Ituen, Ima, and Gunho Sohn. "The Way Forward: Advances in Maintaining Right-of-Way of Transmission Lines." Geomatica 64 (January 1, 2010): 451–62.
Additional Information	This paper, while a bit dated, is a useful summary of vegetation management techniques in ROWs.

References

Adewuyi, Philip. "An Investigation into the Use of Artificial Neural Network to Monitor and Detect Leakage Point(s) along a Select Pipeline." *Pacific Journal of Science and Technology*, June 1, 2013.

Babichenko, S, Alex Dudelzak, and Larisa Poryvkina. "Laser Remote Sensing of Coastal and Terrestrial Pollution by FLS-LIDAR." *EARSeL EProceedings* 3 (January 1, 2004): 1–8.

Bayramov, E. "Optimization of Environmental Monitoring Principles along Oil and Gas Pipelines Using GIS and Remote Sensing." In *2013 7th International Conference on Application of Information and Communication Technologies*, 1–3, 2013. https://doi.org/10.1109/ICAICT.2013.6722681.

Cetin, B., M. Bikdash, and M. McInerney. "Automated Electric Utility Pole Detection from Aerial Images." In *IEEE Southeastcon 2009*, 44–49, 2009. https://doi.org/10.1109/SECON.2009.5174047.

Dackermann, Ulrike, Bradley Skinner, and Jianchun Li. "Guided Wave–Based Condition Assessment of in Situ Timber Utility Poles Using Machine Learning Algorithms." *Structural Health Monitoring* 13, no. 4 (July 1, 2014): 374–88. https://doi.org/10.1177/1475921714521269.

Dwyer, James F., Rick E. Harness, Brian D. Gerber, Melissa A. Landon, Paul Petersen, Daryl D. Austin, Brian Woodbridge, Gary E. Williams, and Duncan Eccleston. "Power Pole Density Informs Spatial Prioritization for Mitigating Avian Electrocution." *The Journal of Wildlife Management* 80, no. 4 (2016): 634–42. https://doi.org/10.1002/jwmg.1048.

Hafeez, K., M. Dilshad Sabir, Z. Najam, and M. ullah Anjum. "Risk Management of Overhead Electric Power Lines." In *2018 1st International Conference on Power, Energy and Smart Grid (ICPESG)*, 1–5, 2018. https://doi.org/10.1109/ICPESG.2018.8384504.

Ituen, Ima, and Gunho Sohn. “The Way Forward: Advances in Maintaining Right-of-Way of Transmission Lines.” *Geomatica* 64 (January 1, 2010): 451–62.

Janahiraman, Tiagrajah V., Tuan Ab Rashid Tuan Abdullah, Ahmad Qisti Ramli, and Norfahani Miskun. “Development of Image Processing Based Solution for Vegetation Classification Using GLCM & Neural Network.” *The International Journal of Science & Technoledge* 5, no. 7 (July 2017): 88–97. https://pure.uniten.edu.my/en/publications/development-of-image-processing-based-solution-for-vegetation-cla.

Jardini, Mauricio G. M., Augustinho José Menin Simões, José Antonio Jardini, Jose Mauricio Scovino de Souza, and Ferdinando Crispino. “Practical Experience of the Use of RGB Camera Images in UAV for the Generation of 3D Images in the Accurate Detection Distance of Vegetation Risk in Right-of-Way Transmission Line.” In *Geo-Spatial Knowledge and Intelligence*, edited by Hanning Yuan, Jing Geng, Chuanlu Liu, Fuling Bian, and Tisinee Surapunt, 152–60. Communications in Computer and Information Science. Springer Singapore, 2018. https://link.springer.com/chapter/10.1007/978-981-13-0896-3_16.

Keskin, Göksu, Caroline D. Teutsch, Andreas Lenz, and Wolfgang Middelmann. “Concept of an Advanced Hyperspectral Remote Sensing System for Pipeline Monitoring.” In *Earth Resources and Environmental Remote Sensing/GIS Applications VI*, 9644:96440H. International Society for Optics and Photonics, 2015. https://doi.org/10.1117/12.2194973.

Long, Daniel, P. J. Rehm, and Scott Ferguson. “Benefits and Challenges of Using Unmanned Aerial Systems in the Monitoring of Electrical Distribution Systems.” *The Electricity Journal* 31, no. 2 (March 1, 2018): 26–32. https://doi.org/10.1016/j.tej.2018.02.004.

Lukowski, T. I., D. Power, B. Yue, C. J. Randall, J. Youden, and C. Howell. “Pipeline Encroachment Monitoring Using Polarimetric SAR Imagery.” In *IGARSS 2004. 2004 IEEE International Geoscience and Remote Sensing Symposium*, 1:68, 2004. https://doi.org/10.1109/IGARSS.2004.1368946.

Marathe, Shreeram. “Leveraging Drone Based Imaging Technology for Pipeline and RoU Monitoring Survey.” Society of Petroleum Engineers, 2019. https://doi.org/10.2118/195427-MS.

Olawale, Babatunde, Chris Chatwin, Rupert Young, and Phil Birch. “REAL-TIME MONITORING OF BURIED OIL PIPELINE RIGHT-OF-WAY FOR THIRD-PARTY INCURSION.” *International Journal of Innovative Science, Engineering and Technology* Volume 2 (February 1, 2015).

Pajares, Gonzalo. “Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs).” *Photogrammetric Engineering & Remote Sensing* 81, no. 4 (April 1, 2015): 281–330. https://doi.org/10.14358/PERS.81.4.281.

Sharma, H., A. V, T. Dutta, and B. P. “Image Analysis-Based Automatic Utility Pole Detection for Remote Surveillance.” In *2015 International Conference on Digital Image Computing: Techniques and Applications (DICTA)*, 1–7, 2015. https://doi.org/10.1109/DICTA.2015.7371267.

Wamsley, Charles C., David Draper, Todd Pett, and Shane Roark. “Synthetic Aperture Radar for Pipeline Right-of-Way Monitoring.” In *Remote Sensing and Modeling of Ecosystems for*

Sustainability XV, 10767:1076706. International Society for Optics and Photonics, 2018. https://doi.org/10.1117/12.2504980.

Yokoyama, H., Hiroaki Date, Satoshi Kanai, and H. Takeda. "(PDF) Pole-like Objects Recognition from Mobile Laser Scanning Data Using Smoothing and Principal Component Analysis." In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. Volume XXXVIII-5/W12. Calgary, Canada, 2011. https://doi.org/10.5194/isprsarchives-XXXVIII-5-W12-115-2011.

Zaman, Asim, Baozhang Ren, and Xiang Liu. "Artificial Intelligence-Aided Automated Detection of Railroad Trespassing." *Transportation Research Record*, May 9, 2019, 0361198119846468. https://doi.org/10.1177/0361198119846468.

4
P54 – FISH PROTECTION

Overall Commentary on the Literature Review Findings

Many of the articles returned by the search strings for P54 apply to fish protection at hydropower facilities. Additionally, much of the research was geographically located in the Western U.S. and/or focused on salmonid species. A large number of these articles described use of acoustic cameras/sonar or acoustic telemetry, in addition to the use of AI ('computer vision', CNN or deep learning) for fish passage and/or behavior in and around hydropower and vertical slot fishways (VSF). Another emerging application found is the use of wave gliders and autonomous vehicles for fish and water quality detection around hydropower facilities, though the search did not locate many examples in the literature.

AI applications included:

- An improved algorithm was developed to better and more quickly (10x faster) decode transmissions from acoustic telemetry (Ingraham et al., 2014);
- "Creation of a machine-learned regression model function" to reduce acoustic telemetry localization error (Rauchenstein et al., 2018);
- Convolutional neural networks (CNN) were used to detect fish from underwater video (Rodriguez et al., 2013) and sonar (Jacobson, 2018), and to identify fish position or trajectories (Rodriguez et al., 2010);
- "Machine learning, image recognition and triangulation" was applied to multiple high-speed images within a fish passage to count, measure (fork length and girth), and identify fish and fin clip in the Whooshh system (Shearer and Dearden, 2018);
- Use of the Q-learning algorithm to optimize dam operations for reservoir water elevation levels and temperature (Bush and Shultz, 2016);
- Use of the deep learning YOLO ("You Only Look Once") algorithm to identify fish from underwater video (Xu and Matzner, 2018);
- Convolutional neural networks (CNN) applied to LIDAR to classify streambeds (Mitra et al., 2005); and
- Use of machine learning of eDNA metabarcoding data in a predictive model for benthic monitoring (Cordier et al., 2017).

In terms of **emerging technologies used**, the book chapter on "Acoustic Methods: Brief Review and Prospects for Advancing Fisheries Research" (Foote, 2009) reviewed the use of hydrophones, multiple types of sonar, and methods for data analysis. McMichael et al. (2011) showcases an exemplar of the use of acoustic telemetry in the juvenile salmon acoustic telemetry system (JSATS) used to track Chinook salmon on the Snake and Columbia rivers. Data collected included: "estimated survival, travel time, route of passage, and three-dimensional (3D) behavior." Martinez et al. (2019) released 'sensor fish' into hydropower units in Vietnam and recorded data that could be used "to predict fish injury/mortality." Mueller et al. (2006) discussed the use of acoustic and video cameras to study fish under ice. Shearer and Dearden

(2018) discussed the Whooshh fish passage technology, which includes the use of video and machine vision to identify fish. Note that EPRI is currently testing the Whooshh technology at a hydropower facility in Maine, focusing on alewife and blueback herring. Neto et al (2014) discussed the use of underwater robotics, and specifically an autonomous underwater vehicle (AUV) to meet the demand for "underwater operations in the fields of dam structure monitoring, ecosystems of reservoir lakes from Hydropower Plants (HPP) and mining and oil". The authors developed and evaluated a UAV with various sensors capable of monitoring dam condition and environmental water quality and species data while reducing costs and labor requirements.

Several papers returned by the search terms highlighted using **eDNA as an emerging technology** (Carim et al., 2017 detecting Pacific lamprey; and Pfleger et al., 2016 for Atlantic and Alabama sturgeon; Laramie et al., 2015 for salmonid species). Plough et al. (2019) used eDNA to monitor threatened Alewife and Blueback herring in the Chesapeake Bay, and noted that "the eDNA abundance data corresponded well to other field methods and has great potential to assist future monitoring efforts of river herring abundance and habitat use." Cordier et al. (2017) used eDNA metabarcoding to determine marine ecological status. The method included machine learning integrated into a predictive model which the authors argued "could overcome and even bypass the cost and time-demanding [standard] morpho-taxonomic approaches in future biomonitoring." It is important to note that eDNA is a rapidly evolving field in fisheries, with numerous other potential examples and applications.

Two papers returned by the search terms used acoustic cameras for **eel detection** - one of which involves a P51 researcher (Jacobson, 2018). The research "investigated three sonar technologies for observing the abundance and behavior of outmigrating adult eels."

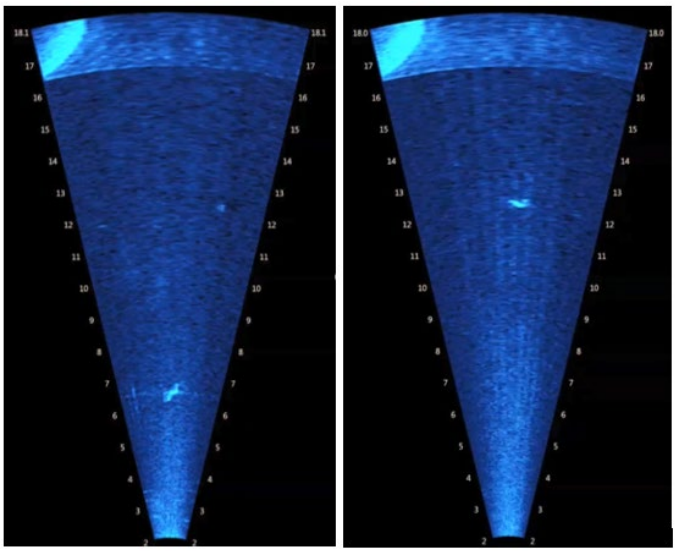

Figure 4-1
Sonar video frame of eel detection (EPRI, 2019)

Lenihan et al. (2019) also used acoustic cameras for eel detection but focused on migrating silver-phase European eels (Anguilla anguilla). The study compared traditional fisheries catch data with detection using an acoustic camera and found the results compared well, concluding that "fisheries-independent estimates of eel spawner biomass escapement will be possible in the future using acoustic cameras."

The only article return from **316(b)-related searches** was Vasslides et al. (2017), who investigated the ecological effect of a coastal nuclear power plant decommissioning. The researchers used software that incorporated algorithms (Ecopath with Ecosim) to determine trophic mass balance as an indication of estuarine ecology.

Whittier et al. (2016) called for **sharing big data** for fisheries research. As an example of the benefit of data sharing, the authors point out that McKenna et al. (2010) "utilized [an existing data set of] point temperature measurements from >3,000 stream sites to create a summer water temperature classification for New York streams that was used by Schlesinger et al. (2011) to assess vulnerability of species at risk."

Finally, although not an application of emerging technology or data science, DeRolph et al. (2016) gathered a database of 300 hydropower relicense mitigation requirements and used a spatially explicit modeling framework to identify explanatory variables for those mitigation requirements.

Table 4-1
Search strings for program 54

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "algorithm" OR "artificial intelligence" OR "remote sensing" OR "machine learning" OR "big data" OR "environmental DNA")	("fish protection" OR "fish passage" OR "fish return")	1,750	200	32
	("316b" OR "316(b)" OR "impingement" OR "entrainment") AND ("power plant" OR "cooling water")	1,670	50	0
	("impingement" OR "entrainment") AND ("cooling water intake structure" OR "CWIS")	27	27	1
("Acoustic telemetry" OR "acoustic camera" OR "Passive Integrated Transponder Tag")	("fish protection" OR "fish passage" OR "hydropower")	1,630	100	14
("wave glider" OR "automatic holographic imagery system" OR "gilder" OR "unmanned underwater vehicles")	("fish protection" OR "fish passage" OR "hydropower")	156	156	2
Total				**51**
Articles highlighted				**4**

Highlighted Literature

Article Title	Advances in Machine Vision Scanning (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of Whooshh technology for fish passage; proposed use of machine vision technology to identify fish
Subject Area	Species detection/identification
Program Area	P54
Abstract	"Observation of migrating fish provides critical data required for recovery and management actions. Considerable resource is expended to count, speciate and sort migrating fish at purpose-built viewing facilities within dams and other man-made barriers. Manual operators observe and record the data in real time or post analyze video recordings. However, the data gathered, and decisions made are inherently prone to human error, operator fatigue and fish directional behavior. Turbidity can also exacerbate accuracy - the main reason that prior automation attempts have been largely unproductive. Recent development of machine vision technology used in manufacturing and fruit harvesting operations provides the potential for dramatically improving and simplifying fisheries data collection. In this session we describe an adaptation of the current state of the art to fisheries management. Using a simple false weir configuration, the fish are dewatered, singulated and descend a short, wetted slide. Controlled lighting and high-speed imagery from radially arranged cameras provide multiple photographs of consistent quality for real time processing. Using combinations of machine learning, image recognition and triangulation, the control system computers are able to simultaneously synthesize the needed data and provide signals for sorting actions in less than 2 seconds, with an extremely high degree of accuracy. Fish counts, and individual fork length and girth measurements can already be reliably captured. Currently under development are algorithms that include fin clip detection (for separation of wild and hatchery fish), and some speciation applications – primarily focused on exclusion of invasive species. The automated nature of the system facilitates 24-hour operation with real-time decisions and remote access to image data. Volitional fish passage is not interrupted, fish are not physically handled, spend minimal time de-watered and are efficiently classified allowing for selective passage."
Value Criteria	Improve environmental, health, or safety outcomes (potential for reducing migration of invasive species) Provide important new insights (opportunity for real-time decision making)
Dataset	NA
Citation	Shearer, Tom, and Steve Dearden. "Advances in Machine Vision Scanning." In International Conference on Engineering and Ecohydrology for Fish Passage, 2018. https://scholarworks.umass.edu/fishpassage_conference/2018/December12/7.
Additional Information	This is a conference abstract about the fish passage technology called Whooshh, and advances in machine vision applied to fish identification. Note that EPRI is currently testing the Whooshh technology at a hydropower facility in Maine, focusing on alewife and blueback herring.

Article Title	Fish Passage: A New Tool to Investigate Fish Movement: JSATS (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of acoustic telemetry to track salmon
Subject Area	Species detection/identification
Program Area	P54
Abstract	"Uncertainty regarding the movement, behavior, and survival of juvenile salmon and steelhead as they migrate through large river systems with multiple hydro facilities has driven much of the fisheries research in the northwestern U.S. over the past two decades. Population declines and subsequent listings under the Endangered Species Act (ESA) of several species of Pacific salmon in the Columbia and Snake river basins have increased the need to manage the effects of the hydro system on these anadromous fish populations. Based on information gaps related to juvenile salmonids, regional fisheries managers have a need to estimate behavior, timing, and survival as smolts migrate downstream through the Federal Columbia River Power System (FCRPS). Recent advancements that resulted in smaller acoustic transmitters have prompted an increase in the use of acoustic telemetry to study juvenile salmonids. Since these advancements, acoustic telemetry has increasingly been used to examine the behavior and survival of yearling and subyearling chinook salmon, sockeye salmon, and steelhead migrating past dams and associated forebays of the Snake and Columbia rivers. Based on the limitations of the technology available in 2001, the Portland District of the U.S. Army Corps of Engineers initiated development of an acoustic telemetry system that would use an active transmitter small enough to be implanted in the majority of the size distribution of juvenile chinook salmon emigrating seaward through the Columbia River estuary. Such a system would enable researchers to address many of the primary management questions related to the effects of the FCRPS on salmonid stocks listed under the ESA. For example, determining the passage route of juvenile fish migrating downstream through the FCRPS is critical to understanding the effects of this hydro system on listed populations. The resulting juvenile salmon acoustic telemetry system (JSATS) consists of microacoustic transmitters, receiving systems, and data processing applications. This article, adapted from an article in the January 2010 issue of Fisheries, describes JSATS and presents a sample of data collected using this system. Specifically, data presented includes estimated survival, travel time, route of passage, and three-dimensional (3D) behavior of JSATS-tagged chinook salmon as they migrated through 695 kilometers of the Snake and Columbia rivers, from Lower Granite Dam to the Pacific Ocean."
Value Criteria	Improve environmental, health, or safety outcomes (new information to inform methods to improve species survival)
Dataset	NA
Citation	McMichael, Geoffrey A., Ryan A. Harnish, Mark A. Weiland, Zhiqun Deng, and Matthew B. Eppard. "Fish Passage: A New Tool to Investigate Fish Movement: JSATS." Hydro Review, 30:34-42 30 (April 20, 2011). https://www.osti.gov/biblio/1013291.
Additional Information	This study provides a good basic overview of JSATS, a large project using acoustic telemetry to track Chinook salmon on the Snake and Columbia rivers.

Article Title	Predicting the Ecological Quality Status of Marine Environments from eDNA Metabarcoding Data Using Supervised Machine Learning (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of eDNA metabarcoding and machine learning to determine marine ecological status
Subject Area	Species detection/identification
Program Area	P54
Abstract	"Monitoring biodiversity is essential to assess the impacts of increasing anthropogenic activities in marine environments. Traditionally, marine biomonitoring involves the sorting and morphological identification of benthic macro-invertebrates, which is time-consuming and taxonomic-expertise demanding. High-throughput amplicon sequencing of environmental DNA (eDNA metabarcoding) represents a promising alternative for benthic monitoring. However, an important fraction of eDNA sequences remains unassigned or belong to taxa of unknown ecology, which prevent their use for assessing the ecological quality status. Here, we show that supervised machine learning (SML) can be used to build robust predictive models for benthic monitoring, regardless of the taxonomic assignment of eDNA sequences. We tested three SML approaches to assess the environmental impact of marine aquaculture using benthic foraminifera eDNA, a group of unicellular eukaryotes known to be good bioindicators, as features to infer macro-invertebrates based biotic indices. We found similar ecological status as obtained from macro-invertebrates inventories. We argue that SML approaches could overcome and even bypass the cost and time-demanding morpho-taxonomic approaches in future biomonitoring."
Value Criteria	Reduce costs (over traditional monitoring approach) Reduce time (reduced labor time)
Dataset	NA
Citation	Cordier, Tristan, Philippe Esling, Franck Lejzerowicz, Joana Visco, Amine Ouadahi, Catarina Martins, Tomas Cedhagen, and Jan Pawlowski. "Predicting the Ecological Quality Status of Marine Environments from EDNA Metabarcoding Data Using Supervised Machine Learning." Environmental Science & Technology 51, no. 16 (August 15, 2017): 9118–26. https://doi.org/10.1021/acs.est.7b01518.
Additional Information	NA

Article Title	Use of an Acoustic Camera to Monitor Seaward Migrating Silver-Phase Eels (Anguilla Anguilla) in a Regulated River (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of acoustic camera observations for daily catch monitoring of European eels
Subject Area	Species detection/identification
Program Area	P54
Abstract	"Downstream migration dynamics of silver-phase eels have traditionally been documented using fisheries catch data. However, improved monitoring protocols and more comprehensive analyses are needed because of widespread declines in Anguillid eel stocks. Therefore, daily catches of silver-phase European eel (Anguilla anguilla) were recorded at an eel fishing weir on the lower River Erne in northwest Ireland. In parallel, eels detected downstream with an acoustic (DIDSON) camera

	were surveyed and the results were compared with catch data obtained at the eel weir. The principal objective was to evaluate the use of the acoustic camera to monitor migration patterns and eel swimming behavior in a regulated river. A highly significant relationship between the acoustic camera eel counts and fishing weir catches was observed ($p < 0.001$). This indicates that fisheries-independent estimates of eel spawner biomass escapement will be possible in the future using acoustic cameras. Acoustic camera observations on eel swimming behavior indicated significantly more eels swimming downstream when discharge was continuous through the night ($p < 0.05$). On nights with no discharge more eels were observed swimming upstream ($p < 0.05$). The swimming speeds of eels differed significantly ($p < 0.05$) between continuous and low discharge conditions. European rivers are increasingly affected by anthropogenic control of discharge to facilitate hydropower generation, flood control and navigation, and this affects natural patterns of eel migration. The results of this study demonstrate the potential use of acoustic cameras for monitoring eel migration dynamics and for behavioral analyses of eel migration in such regulated rivers."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time) Provide important new insights (new information to inform methods to improve species survival)
Dataset	NA
Citation	Lenihan, Eamonn S., T. Kieran McCarthy, and Colin Lawton. "Use of an Acoustic Camera to Monitor Seaward Migrating Silver-Phase Eels (Anguilla Anguilla) in a Regulated River." Ecohydrology & Hydrobiology, New advancements in Soil and Water Assessment Tool (SWAT) for ecohydrological modelling and application, 19, no. 2 (April 1, 2019): 289–95. https://doi.org/10.1016/j.ecohyd.2018.07.001.
Additional Information	The use of acoustic camera observations of European eels worked as well as traditional daily catch monitoring.

References

Bush, Isabel F., and Matthew Shultz. "Minimizing Thermal Impacts of Hydropower Using Reinforcement Learning," 2016.

Carapezza, Edward M, Gabrial Lombardi, Jerry Butman, and Ivar Babb. "Miniature Dissolved Oxygen and Turbulence Optical Sensor for River and Coastal Environmental Applications," Vol. 7480, 2009. https://doi.org/10.1117/12.835083.

Carim et al. "A Noninvasive Tool to Assess the Distribution of Pacific Lamprey (Entosphenus Tridentatus) in the Columbia River Basin," 2017. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0169334.

Cavalcanti Neto, Edson & Sá, Rejane & Holanda, Guilherme & Mota, Francisco & Varela, Antonio & Araújo, André & Loiola, Italo & Oliveira, Rogerio & Alexandria, Auzuir & Albuquerque, V.H.C.. (2014). Autonomous Underwater Vehicle to Inspect Hydroelectric Dams. International Journal of Computer Applications. 101. 1. 10.5120/17728-8801.

Cordier, Tristan, Philippe Esling, Franck Lejzerowicz, Joana Visco, Amine Ouadahi, Catarina Martins, Tomas Cedhagen, and Jan Pawlowski. "Predicting the Ecological Quality Status of Marine Environments from EDNA Metabarcoding Data Using Supervised Machine Learning."

Environmental Science & Technology 51, no. 16 (August 15, 2017): 9118–26. https://doi.org/10.1021/acs.est.7b01518.

DeRolph, Christopher R., Michael P. Schramm, and Mark S. Bevelhimer. "Predicting Environmental Mitigation Requirements for Hydropower Projects through the Integration of Biophysical and Socio-Political Geographies." *Science of The Total Environment* 566–567 (October 1, 2016): 888–918. https://doi.org/10.1016/j.scitotenv.2016.05.099.

Foote, Kenneth G. "Acoustic Methods: Brief Review and Prospects for Advancing Fisheries Research." In *The Future of Fisheries Science in North America*, edited by Richard J. Beamish and Brian J. Rothschild, 313–43. Fish & Fisheries Series. Dordrecht: Springer Netherlands, 2009. https://doi.org/10.1007/978-1-4020-9210-7_18.

Frechette, Danielle, Ann-Marie K. Osterback, Sean A. Hayes, Morgan H. Bond, Jonathan W. Moore, Scott A. Shaffer, and James T. Harvey. "Assessing Avian Predation on Juvenile Salmonids Using Passive Integrated Transponder Tag Recoveries and Mark–Recapture Methods." *North American Journal of Fisheries Management* 32, no. 6 (December 1, 2012): 1237–50. https://doi.org/10.1080/02755947.2012.728171.

Ingraham, J. M., Z. D. Deng, X. Li, T. Fu, G. A. McMichael, and B. A. Trumbo. "A Fast and Accurate Decoder for Underwater Acoustic Telemetry." *Review of Scientific Instruments* 85, no. 7 (July 1, 2014): 074903. https://doi.org/10.1063/1.4891041.

Jacobson, Paul. "Machine Learning for Automated Sonar Monitoring of Outmigrating American Eel Behavior." In *International Conference on Engineering and Ecohydrology for Fish Passage*, 2018. https://scholarworks.umass.edu/fishpassage_conference/2018/December12/32.

Laramie, Matthew B., David S. Pilliod, and Caren S. Goldberg. "Characterizing the Distribution of an Endangered Salmonid Using Environmental DNA Analysis." *Biological Conservation*, Special Issue: Environmental DNA: A powerful new tool for biological conservation, 183 (March 1, 2015): 29–37. https://doi.org/10.1016/j.biocon.2014.11.025.

Lenihan, Eamonn S., T. Kieran McCarthy, and Colin Lawton. "Use of an Acoustic Camera to Monitor Seaward Migrating Silver-Phase Eels (Anguilla Anguilla) in a Regulated River." *Ecohydrology & Hydrobiology*, New advancements in Soil and Water Assessment Tool (SWAT) for ecohydrological modelling and application, 19, no. 2 (April 1, 2019): 289–95. https://doi.org/10.1016/j.ecohyd.2018.07.001.

Martinez, Jayson, Zhiqun Daniel Deng, Chuan Tian, Robert Mueller, Oudom Phonekhampheng, Douangkham Singhanouvong, Garry Thorncraft, Thonglom Phommavong, and Khamla Phommachan. "In Situ Characterization of Turbine Hydraulic Environment to Support Development of Fish-Friendly Hydropower Guidelines in the Lower Mekong River Region." *Ecological Engineering* 133 (August 1, 2019): 88–97. https://doi.org/10.1016/j.ecoleng.2019.04.028.

McMichael, Geoffrey A., Ryan A. Harnish, Mark A. Weiland, Zhiqun Deng, and Matthew B. Eppard. "Fish Passage: A New Tool to Investigate Fish Movement: JSATS." *Hydro Review, 30:34-42* 30 (April 20, 2011). https://www.osti.gov/biblio/1013291.

Mitra, Vikramjit, Chiajiu Wang, and Satarupa Banerjee. “Lidar Signal Processing for Under-Water Object Detection.” In *Advances in Neural Networks – ISNN 2005*, edited by Jun Wang, Xiao-Feng Liao, and Zhang Yi, 556–61. Lecture Notes in Computer Science. Springer Berlin Heidelberg, 2005.

Mueller, Robert P., Richard S. Brown, Haakon Hop, and Larry Moulton. “Video and Acoustic Camera Techniques for Studying Fish under Ice: A Review and Comparison.” *Reviews in Fish Biology and Fisheries* 16, no. 2 (May 1, 2006): 213–26. https://doi.org/10.1007/s11160-006-9011-0.

Pfleger, Mariah O., Steven J. Rider, Carol E. Johnston, and Alexis M. Janosik. “Saving the Doomed: Using EDNA to Aid in Detection of Rare Sturgeon for Conservation (Acipenseridae).” *Global Ecology and Conservation* 8 (October 1, 2016): 99–107. https://doi.org/10.1016/j.gecco.2016.08.008.

Plough LV, Ogburn MB, Fitzgerald CL, Geranio R, Marafino GA, Richie KD. “Environmental DNA Analysis of River Herring in Chesapeake Bay: A Powerful Tool for Monitoring Threatened Keystone Species.” *PLoS ONE* 13, no. 11 (2018). https://doi.org/10.1371/journal.pone.0205578.

Rauchenstein, Lynn T., Abhinav Vishnu, Xinya Li, and Zhiqun Daniel Deng. “Improving Underwater Localization Accuracy with Machine Learning.” *Review of Scientific Instruments* 89, no. 7 (July 1, 2018): 074902. https://doi.org/10.1063/1.5012687.

Rodríguez, Alvaro, María Bermúdez, Juan R. Rabuñal, and Jerónimo Puertas. “Optical Fish Tracking in Fishways Using Neural Networks.” In *World Academy of Science, Engineering and Technology International Journal of Environmental and Ecological Engineering*, Vol. 4, 2010. https://publications.waset.org/11261/optical-fish-tracking-in-fishways-using-neural-networks.

Rodriguez, Álvaro, Juan R. Rabuñal, María Bermúdez, and Alejandro Pazos. “Automatic Fish Segmentation on Vertical Slot Fishways Using SOM Neural Networks.” In *Advances in Computational Intelligence*, edited by Ignacio Rojas, Gonzalo Joya, and Joan Gabestany, 445–52. Lecture Notes in Computer Science. Springer Berlin Heidelberg, 2013.

Shearer, Tom, and Steve Dearden. “Advances in Machine Vision Scanning.” In *International Conference on Engineering and Ecohydrology for Fish Passage*, 2018. https://scholarworks.umass.edu/fishpassage_conference/2018/December12/7.

Vasslides, James M., Howard Townsend, Thomas Belton, and Olaf P. Jensen. “Modeling the Effects of a Power Plant Decommissioning on an Estuarine Food Web.” *Estuaries and Coasts* 40, no. 2 (March 1, 2017): 604–16. https://doi.org/10.1007/s12237-016-0151-8.

Whittier, Joanna, Nick Sievert, Andrew Loftus, Julie M. Defilippi, Rebecca M. Krogman, Jeffrey Ojala, Thom Litts, Jeff Kopaska, and Nicole Eiden. “Leveraging BIG Data from BIG Databases to Answer BIG Questions.” *Fisheries* 41, no. 7 (July 2, 2016): 417–19. https://doi.org/10.1080/03632415.2016.1191911.

Xu, Wenwei, and Shari Matzner. “Underwater Fish Detection Using Deep Learning for Water Power Applications.” *ArXiv:1811.01494 [Cs]*, November 4, 2018. http://arxiv.org/abs/1811.01494.

5
P55 – ECOSYSTEM RISK AND RESILIENCY: WILDFIRE & EXTREME EVENTS

Overall Commentary on the Literature Review Findings

A note for P55 members: In 2018, the program published a report on "Data Analytics: Overview and Natural Resource Applications Relevant to the Electric Power Industry" (3002013696) which included a literature review. The following section differs in its use of a different set of search strings (see below). The papers noted below were not identified in the 2018 report, with one exception (Hampton et al., 2013).

The search string terms for P55 (detailed in the table below) primarily returned results related to data science applications (mostly AI and machine learning) to flooding and other severe weather. Wetland identification and the energy-water nexus were additional relevant subjects with AI applications. Papers on the topic of green infrastructure or 'smart cities' tended to be less relevant to P55 research or did not highlight the use of emerging technology or data science.

Some of the more relevant **severe weather** papers included McGovern et al.'s (2017) review of "Using Artificial Intelligence to Improve Real-Time Decision-Making for High-Impact Weather." The authors stated that AI has improved prediction models for "storm duration, severe wind, severe hail, precipitation classification, forecasting for renewable energy, and aviation turbulence." Krajewski et al. (2016) used data from multiple sources (including over 200 bridge mounted sensors) to input a unique rainfall-runoff algorithm for statewide real-time **flood forecasting** in Iowa. Pyayt et al. (2011) similarly used sensors and AI for a flood warning system ('UrbanFlood') measuring dike water levels in EU countries. Wu et al. (2014) described a new runoff model (a part of a broader real-time Global Flood Monitoring System) providing outputs every 3 hours at a spatial resolution of about 12km. In 2011, Matgen et al. stated "Algorithms that enable an automatic delineation of flooded areas are an essential component of any SAR-based [flood] monitoring services but are to date quasi non-existent." The authors test two algorithms in the UK and found they performed as well as "state-of-the-art-benchmark" manual methods. Dawson et al. (2006) used ANN to estimate flooding in ungauged watersheds and found the AI approach to be superior to regression analysis. The model was applied extensively in the United Kingdom (850 watersheds). In terms of **drought forecasting**, AghaKouchak et al. (2015) provided an overview of satellite-based data for drought remote sensing and note the need for "models and algorithms that combine multiple data sets and/or assimilate satellite observations into model simulations."

Relevant search returns also including a number of papers focused on **wetlands.** Mahdavi et al. (2017) provide a good review of remote sensing for wetland identification and classification. The paper is akin to a tutorial review of use of multiple forms of data (aerial imagery, multispectral, SAR, and others) and algorithms (K nearest neighbor, ML, support vector machine, decision tree, and random forest). Salehi et al. (2019) – which includes many of the researchers from the previous article – describe a long-term effort based in Newfoundland, Canada to develop algorithms and machine learning capable of classifying wetlands under the Canadian Wetland

Classification System from multi-spectral imagery and SAR with 90% accuracy. The researchers say they have tested and achieved this accuracy goal, and that the method can be applied to other areas, although given that Canada's classification system only includes bogs, fens, swamps, marshes, and shallow water, this statement may be more applicable to Canada than other latitudes. Although Salehi et al.'s paper is titled "A Collection of Novel Algorithms for Wetland Classification with SAR and Optical Data," there is not a list or collection of algorithms in this particular paper. Zomer et al. (2009) describe a very interesting effort to collect a "library" of hyperspectral data of wetland species. The authors collected 1,336 spectra data points in five sites in California, Texas, and Mississippi, and then used this collection as a training set for classifying wetland species in another area (Sacramento Delta area, California) with good success.

Figure 5-1
Natural color drone image of wetlands (USGS, 2017)

Papers also included data science applications to the **Energy-Water Nexus (EWN).** Yin et al. (2018) used ANN to model energy and water use in Wuxi City in eastern China and found that the ANN model performed better than a multiple linear regression (MLR) model. Allen et al. (2018) provided supporting information for their proposed idea of developing a 'knowledge discovery framework' central space to aggregate EWN data and tools for analysis. In doing so, they provide a very nice review of each piece of analysis in the EWN arena (e.g., electric supply and demand, integration of energy and water methods), and analytical tools used in each step—running the gamut from regression analysis to many forms of AI. Abegaz et al. (2017) "provide a critical overview on the state of the art, research gaps and future research directions in sensor technology" with regards to the EWN.

In **broader themes**, Hampton et al. (2013) excoriated ecologists to share data:

> "Simply put, the era of data-intensive science is here. Those who step up to address major environmental challenges will leverage their expertise by leveraging their data. Those who do not run the risk of becoming scientifically irrelevant."

Blair et al. (2019) stated "To date, there has been little work on data science applied to the understanding and management of the natural environment." Like Hampton et al., Blair et al.

also include data sharing as part of a broad research roadmap they developed which also includes complex [vague] themes such as "[providing] techniques and frameworks to both reify uncertainty in scientific studies and also reason about the cascading uncertainties across complex experiments, e.g., in integrated modeling frameworks."

Figure 5-2
NASA satellite imagery of wildfires in California, July 2019 (NASA, 2019)

Table 5-1
Search strings for program 55

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "artificial intelligence" OR "remote sensing" OR "machine learning" OR "big data")	("ecological resource risk" OR "extreme events" OR "wildfire" OR "drought" OR "flood")	19,700	160	28
	("power grid" OR "water availability" OR "electric power risk mitigation extreme events")	25,000	50	5
	("electrical power") AND ("ecological risk" OR "climate change" OR "water resource")	7,840	140	4
	("wetland" OR "wetland identification")	18,100	100	13
	("green infrastructure")	6,910	100	5
	("energy water nexus")	755	100	4
Program staff recommended articles				2
Total				**61**
Articles highlighted				**7**

Highlighted Literature

Article Title	A Collection of Novel Algorithms for Wetland Classification with SAR and Optical Data (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of algorithms and use machine learning to classify wetlands from multi-spectral imagery and SAR
Subject Area	Wetland/land cover identification
Program Area	P55
Abstract	"Wetlands are valuable natural resources that provide many benefits to the environment, and thus, mapping wetlands is crucially important. We have developed land cover and wetland classification algorithms that have general applicability to different geographical locations. We also want a high level of classification accuracy (i.e., more than 90%). Over that past 2 years, we have been developing an operational wetland classification approach aimed at a Newfoundland/Labrador province-wide wetland inventory. We have developed and published several algorithms to classify wetlands using multi-source data (i.e., polarimetric SAR and multi-spectral optical imagery), object-based image analysis, and advanced machine-learning tools. The algorithms have been tested and verified on many large pilot sites across the province and provided overall and class-based accuracies of about 90%. The developed methods have general applicability to other Canadian provinces (with field validation data) allowing the creation of a nation-wide wetland inventory system."
Value Criteria	Reduce regulatory risk (could help avoid regulatory risk) Reduce costs (of identifying wetlands) Reduce time (reduced labor time travelling to field locations)
Dataset	NA
Citation	Salehi, Bahram, Masoud Mahdianpari, Meisam Amani, Fariba Manesh, Jean Granger, Sahel Mahdavi, and Brian Brisco. "A Collection of Novel Algorithms for Wetland Classification with SAR and Optical Data." In Wetlands Management - Assessing Risk and Sustainable Solutions, 2019. https://www.researchgate.net/publication/330144913_A_Collection_of_Novel_Algorithms_for_Wetland_Classification_with_SAR_and_Optical_Data.
Additional Information	Contrary to the title, this study does not publish a list/collection, but is rather a narrative overview of an effort in Canada to automatically classify wetlands. Note the Canadian Wetland Classification System (CWCS) includes these classes: bog, fen, swamp, marsh, shallow water). The group (from SUNY and the Canada Centre for Remote Sensing, Ottawa) developed algorithms and use machine learning to classify wetlands from multi-spectral imagery and SAR.

Article Title	A Survey of Analytical Methods for Inclusion in a New Energy-Water Nexus Knowledge Discovery Framework (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of multiple types of analysis ranging from regression to AI in energy water nexus analyses
Subject Area	Energy water nexus
Program Area	P55
Abstract	"The energy-water nexus, or the dependence of energy on water and water on energy,

	continues to receive attention as impacts on both energy and water supply and demand from growing populations and climate-related stresses are evaluated for future infrastructure planning. Changes in water and energy demand are related to changes in regional temperature, and precipitation extremes can affect water resources available for energy generation for those regional populations. Additionally, the vulnerabilities to the energy and water nexus are beyond the physical infrastructures themselves and extend into supporting and interdependent infrastructures. Evaluation of these vulnerabilities relies on the integration of the disparate and distributed data associated with each of the infrastructures, environments and populations served, and robust analytical methodologies of the data. A capability for the deployment of these methods on relevant data from multiple components on a single platform can provide actionable information for interested communities, not only for individual energy and water systems, but also for the system of systems that they comprise. Here, we survey the highest priority data needs and analytical methods for inclusion on such a platform."
Value Criteria	Improve environmental, health, or safety outcomes (new information to inform resource management) Provide important new insights (potential for decision support system, identification of operational risk)
Dataset	NA
Citation	Allen, Melissa R., Syed Mohammed Arshad Zaidi, Varun Chandola, April M. Morton, Christa M. Brelsford, Ryan A. McManamay, Binita KC, Jibonananda Sanyal, Robert N. Stewart, and Budhendra L. Bhaduri. "A Survey of Analytical Methods for Inclusion in a New Energy-Water Nexus Knowledge Discovery Framework." Big Earth Data 2, no. 3 (July 3, 2018): 197–227. https://doi.org/10.1080/20964471.2018.1524344.
Additional Information	This paper, done by Oak Ridge, is more of a proposal/review piece that explores the analyses made possible by putting data and analytical tools together onto a platform (a knowledge discovery framework) specifically for the energy-water nexus. The review includes an overview of different types of analysis in all parts of the energy water nexus (from electricity supply to demand to and from different fuel types/consumer types, and integration of energy and water data and methods) and different tools and methods that are available, ranging from regression to incorporating AI.

Article Title	Building Spectral Libraries for Wetlands Land Cover Classification and Hyperspectral Remote Sensing (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of hyperspectral data to identify wetland plant species spectral signatures and create a large dataset as training data for AI-enabled automated classification of wetland species
Subject Area	Wetland/land cover identification
Program Area	P55, P195
Abstract	"Recent advances in remote sensing provide opportunities to map plant species and vegetation within wetlands at management relevant scales and resolutions. Hyperspectral images, currently available on airborne platforms, provide increased spectral resolution over existing space-based sensors that can document detailed information on the distribution of vegetation community types, and sometimes species. Development of spectral libraries of wetland species is a key component needed to facilitate advanced analytical techniques to monitor wetlands. Canopy and

	leaf spectra at five sites in California, Texas, and Mississippi were sampled to create a common spectral library for mapping wetlands from remotely sensed data. An extensive library of spectra (n=1336) for coastal wetland communities, across a range of bioclimatic, edaphic, and disturbance conditions were measured. The wetland spectral libraries were used to classify and delineate vegetation at a separate location, the Pacheco Creek wetland in the Sacramento Delta, California, using a PROBE-1 airborne hyperspectral data set (5m pixel resolution, 128 bands). This study discusses sampling and collection methodologies for building libraries, and illustrates the potential of advanced sensors to map wetland composition. The importance of developing comprehensive wetland spectral libraries, across diverse ecosystems is highlighted. In tandem with improved analytical tools these libraries provide a physical basis for interpretation that is less subject to conditions of specific data sets. To facilitate a global approach to the application of hyperspectral imagers to mapping wetlands, we suggest that criteria for and compilation of wetland spectral libraries should proceed today in anticipation of the wider availability and eventual space-based deployment of advanced hyperspectral high spatial resolution sensors."
Value Criteria	Reduce regulatory risk (could help avoid regulatory risk) Reduce costs (of identifying wetlands) Reduce time (reduced labor time travelling to field locations)
Dataset	A "library" of hyperspectral data (1,336 spectra data points) of wetland species
Citation	Zomer, R. J., A. Trabucco, and S. L. Ustin. "Building Spectral Libraries for Wetlands Land Cover Classification and Hyperspectral Remote Sensing." Journal of Environmental Management, The GlobWetland Symposium: Looking at wetlands from space, 90, no. 7 (May 1, 2009): 2170–77. https://doi.org/10.1016/j.jenvman.2007.06.028.
Additional Information	This study created a "library of spectra (n= 1336) for coastal wetland communities" and then used the library to help classify/delineate wetlands in another location.

Article Title	Real-Time Flood Forecasting and Information System for the State of Iowa (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of multiple remote sensed data types (including over 200 bridge mounted sensors) to input a unique rainfall-runoff algorithm for statewide real-time flood forecasting
Subject Area	Extreme events - flooding
Program Area	P55
Abstract	"The Iowa Flood Center (IFC), established following the 2008 record floods, has developed a real-time flood forecasting and information dissemination system for use by all Iowans. The system complements the operational forecasting issued by the National Weather Service, is based on sound scientific principles of flood genesis and spatial organization and includes many technological advances. At its core is a continuous rainfall–runoff model based on landscape decomposition into hillslopes and channel links. Rainfall conversion to runoff is modeled through soil moisture accounting at hillslopes. Channel routing is based on a nonlinear representation of water velocity that considers the discharge amount as well as the upstream drainage area. Mathematically, the model represents a large system of ordinary differential equations organized to follow river network topology. The IFC also developed an efficient numerical solver suitable for high-performance computing architecture. The solver allows the IFC to update forecasts every 15 min for over 1,000 Iowa communities. The input to the system comes from a radar-rainfall algorithm,

	developed in-house, that maps rainfall every 5 min with high spatial resolution. The algorithm uses Level II radar reflectivity and other polarimetric data from the Weather Surveillance Radar-1988 Dual-Polarimetric (WSR-88DP) radar network. A large library of flood inundation maps and real-time river stage data from over 200 IFC "stream-stage sensors" complement the IFC information system. The system communicates all this information to the general public through a comprehensive browser-based and interactive platform. Streamflow forecasts and observations from Iowa can provide support for a similar system being developed at the National Water Center through model intercomparisons, diagnostic analyses, and product evaluations."
Value Criteria	Reduce time (to access information) Improve environmental, health, or safety outcomes (information connects to alerts for public safety) Provide important new insights (near real-time forecasts)
Dataset	NA
Citation	Krajewski, Witold F., Daniel Ceynar, Ibrahim Demir, Radoslaw Goska, Anton Kruger, Carmen Langel, Ricardo Mantilla, et al. "Real-Time Flood Forecasting and Information System for the State of Iowa." Bulletin of the American Meteorological Society 98, no. 3 (June 24, 2016): 539–54. https://doi.org/10.1175/BAMS-D-15-00243.1.
Additional Information	This resource added by EPRI staff; not part of official methodology.

Article Title	Remote Sensing for Wetland Classification: A Comprehensive Review (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of multiple types of remote sensed data and application of forms of AI (KNN, ML, support vector machine [SVM], decision tree ML, and random forest [RF]) for wetland identification
Subject Area	Wetland/land cover identification
Program Area	P55
Abstract	"Wetlands are valuable natural resources that provide many benefits to the environment. Therefore, mapping wetlands is crucially important. Several review papers on remote sensing (RS) of wetlands have been published thus far. However, there is no recent review paper that contains an inclusive description of the importance of wetlands, the urgent need for wetland classification, along with a thorough explanation of the existing methods for wetland mapping using RS methods. This paper attempts to provide readers with an exhaustive review regarding different aspects of wetland studies. First, the readers are acquainted with the characteristics, importance, and challenges of wetlands. Then, various RS approaches for wetland classification are discussed, along with their advantages and disadvantages. These approaches include wetland classification using aerial, multispectral, synthetic aperture radar (SAR), and several other data sets. Different pixel-based and object-based algorithms for wetland classification are also explored in this study. The most important conclusions drawn from the literature are that the red edge and near-infrared bands are the best optical bands for wetland delineation. In terms of SAR imagery, large incidence angles, short wavelengths, and horizontal transmission and vertical reception polarization are best for detecting of herbaceous wetlands, while small incidence angles, long wavelengths, and horizontal transmission and reception polarization are appropriate for mapping forested wetlands."

Value Criteria	Reduce regulatory risk (could help avoid regulatory risk) Reduce costs (of identifying wetlands) Reduce time (reduced labor time travelling to field locations)
Dataset	NA
Citation	Mahdavi, Sahel, Bahram Salehi, Jean Granger, Meisam Amani, Brian Brisco, and Weimin Huang. "Remote Sensing for Wetland Classification: A Comprehensive Review." GIScience & Remote Sensing 55, no. 5 (September 3, 2018): 623–58. https://doi.org/10.1080/15481603.2017.1419602.
Additional Information	This study is relevant to P55 wetland research, and serves as a good reference article on wetland identification and classification using remote sensing. Data types covered include aerial imagery, mutispectral, and SAR. The paper also discusses various algorithms, including KNN, ML, support vector machine (SVM), decision tree ML, and random forest (RF).

Article Title	Remote Sensing of Drought: Progress, Challenges and Opportunities (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Propose development of models and algorithms to combine or aggregate multiple types of remote sensing data for drought prediction
Subject Area	Disaster monitoring
Program Area	P55
Abstract	"This review surveys current and emerging drought monitoring approaches using satellite remote sensing observations from climatological and ecosystem perspectives. We argue that satellite observations not currently used for operational drought monitoring, such as near-surface air relative humidity data from the Atmospheric Infrared Sounder mission, provide opportunities to improve early drought warning. Current and future satellite missions offer opportunities to develop composite and multi-indicator drought models. While there are immense opportunities, there are major challenges including data continuity, unquantified uncertainty, sensor changes, and community acceptability. One of the major limitations of many of the currently available satellite observations is their short length of record. A number of relevant satellite missions and sensors (e.g., the Gravity Recovery and Climate Experiment) provide only a decade of data, which may not be sufficient to study droughts from a climate perspective. However, they still provide valuable information about relevant hydrologic and ecological processes linked to this natural hazard. Therefore, there is a need for models and algorithms that combine multiple data sets and/or assimilate satellite observations into model simulations to generate long-term climate data records. Finally, the study identifies a major gap in indicators for describing drought impacts on the carbon and nitrogen cycle, which are fundamental to assessing drought impacts on ecosystems."
Value Criteria	Improve environmental, health, or safety outcomes (new information to inform resource management) Provide important new insights (potential for decision support system, identification of operational risk)
Dataset	NA
Citation	AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D.

	Wardlow, and C. R. Hain. "Remote Sensing of Drought: Progress, Challenges and Opportunities." Reviews of Geophysics 53, no. 2 (2015): 452–80. https://doi.org/10.1002/2014RG000456.
Additional Information	NA

Article Title	Using Artificial Intelligence to Improve Real-Time Decision-Making for High-Impact Weather (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of AI to improve prediction models for "storm duration, severe wind, severe hail, precipitation classification, forecasting for renewable energy, and aviation turbulence."
Subject Area	Disaster monitoring
Program Area	P55
Abstract	"High-impact weather events, such as severe thunderstorms, tornadoes, and hurricanes, cause significant disruptions to infrastructure, property loss, and even fatalities. High-impact events can also positively impact society, such as the impact on savings through renewable energy. Prediction of these events has improved substantially with greater observational capabilities, increased computing power, and better model physics, but there is still significant room for improvement. Artificial intelligence (AI) and data science technologies, specifically machine learning and data mining, bridge the gap between numerical model prediction and real-time guidance by improving accuracy. AI techniques also extract otherwise unavailable information from forecast models by fusing model output with observations to provide additional decision support for forecasters and users. In this work, we demonstrate that applying AI techniques along with a physical understanding of the environment can significantly improve the prediction skill for multiple types of high-impact weather. The AI approach is also a contribution to the growing field of computational sustainability. The authors specifically discuss the prediction of storm duration, severe wind, severe hail, precipitation classification, forecasting for renewable energy, and aviation turbulence. They also discuss how AI techniques can process "big data," provide insights into high-impact weather phenomena, and improve our understanding of high-impact weather."
Value Criteria	Improve environmental, health, or safety outcomes (new information to improve public safety) Provide important new insights (identification of operational risk, improve accuracy of modeling)
Dataset	NA
Citation	McGovern, Amy, Kimberly L. Elmore, David John Gagne, Sue Ellen Haupt, Christopher D. Karstens, Ryan Lagerquist, Travis Smith, and John K. Williams. "Using Artificial Intelligence to Improve Real-Time Decision-Making for High-Impact Weather." Bulletin of the American Meteorological Society 98, no. 10 (March 24, 2017): 2073–90. https://doi.org/10.1175/BAMS-D-16-0123.1.
Additional Information	NA

References

Abegaz, Brook W., Tania Datta, and Satish M. Mahajan. "Sensor Technologies for the Energy-Water Nexus – A Review." *Applied Energy* 210 (January 15, 2018): 451–66. https://doi.org/10.1016/j.apenergy.2017.01.033.

AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D. Wardlow, and C. R. Hain. "Remote Sensing of Drought: Progress, Challenges and Opportunities." *Reviews of Geophysics* 53, no. 2 (2015): 452–80. https://doi.org/10.1002/2014RG000456.

Allen, Melissa R., Syed Mohammed Arshad Zaidi, Varun Chandola, April M. Morton, Christa M. Brelsford, Ryan A. McManamay, Binita KC, Jibonananda Sanyal, Robert N. Stewart, and Budhendra L. Bhaduri. "A Survey of Analytical Methods for Inclusion in a New Energy-Water Nexus Knowledge Discovery Framework." *Big Earth Data* 2, no. 3 (July 3, 2018): 197–227. https://doi.org/10.1080/20964471.2018.1524344.

Blair, Gordon S., Peter Henrys, Amber Leeson, John Watkins, Emma Eastoe, Susan Jarvis, and Paul J. Young. "Data Science of the Natural Environment: A Research Roadmap." *Frontiers in Environmental Science* 7 (2019). https://doi.org/10.3389/fenvs.2019.00121.

Dawson, C. W., R. J. Abrahart, A. Y. Shamseldin, and R. L. Wilby. "Flood Estimation at Ungauged Sites Using Artificial Neural Networks." *Journal of Hydrology* 319, no. 1 (March 15, 2006): 391–409. https://doi.org/10.1016/j.jhydrol.2005.07.032.

Hampton, Stephanie E., Carly A. Strasser, Joshua J. Tewksbury, Wendy K. Gram, Amber E. Budden, Archer L. Batcheller, Clifford S. Duke, and John H. Porter. "Big Data and the Future of Ecology." *Frontiers in Ecology and the Environment* 11, no. 3 (2013): 156–62. https://doi.org/10.1890/120103.

Krajewski, Witold F., Daniel Ceynar, Ibrahim Demir, Radoslaw Goska, Anton Kruger, Carmen Langel, Ricardo Mantilla, et al. "Real-Time Flood Forecasting and Information System for the State of Iowa." *Bulletin of the American Meteorological Society* 98, no. 3 (June 24, 2016): 539–54. https://doi.org/10.1175/BAMS-D-15-00243.1.

Mahdavi, Sahel, Bahram Salehi, Jean Granger, Meisam Amani, Brian Brisco, and Weimin Huang. "Remote Sensing for Wetland Classification: A Comprehensive Review." *GIScience & Remote Sensing* 55, no. 5 (September 3, 2018): 623–58. https://doi.org/10.1080/15481603.2017.1419602.

Matgen, P., R. Hostache, G. Schumann, L. Pfister, L. Hoffmann, and H. H. G. Savenije. "Towards an Automated SAR-Based Flood Monitoring System: Lessons Learned from Two Case Studies." *Physics and Chemistry of the Earth, Parts A/B/C*, Recent Advances in Mapping and Modelling Flood Processes in Lowland Areas, 36, no. 7 (January 1, 2011): 241–52. https://doi.org/10.1016/j.pce.2010.12.009.

McGovern, Amy, Kimberly L. Elmore, David John Gagne, Sue Ellen Haupt, Christopher D. Karstens, Ryan Lagerquist, Travis Smith, and John K. Williams. "Using Artificial Intelligence to Improve Real-Time Decision-Making for High-Impact Weather." *Bulletin of the American Meteorological Society* 98, no. 10 (March 24, 2017): 2073–90. https://doi.org/10.1175/BAMS-D-16-0123.1.

Pyayt, Alexander L, Ilya I Mokhov, Bernhard Lang, Valeria V Krzhizhanovskaya, and Robert J Meijer. “Machine Learning Methods for Environmental Monitoring and Flood Protection” 5, no. 6 (2011): 6.

Salehi, Bahram, Masoud Mahdianpari, Meisam Amani, Fariba Manesh, Jean Granger, Sahel Mahdavi, and Brian Brisco. “A Collection of Novel Algorithms for Wetland Classification with SAR and Optical Data.” In *Wetlands Management - Assessing Risk and Sustainable Solutions*, 2019. https://www.researchgate.net/publication/330144913_A_Collection_of_Novel_Algorithms_for_Wetland_Classification_with_SAR_and_Optical_Data.

Wu, Huan, Robert F. Adler, Yudong Tian, George J. Huffman, Hongyi Li, and JianJian Wang. “Real-Time Global Flood Estimation Using Satellite-Based Precipitation and a Coupled Land Surface and Routing Model.” *Water Resources Research* 50, no. 3 (2014): 2693–2717. https://doi.org/10.1002/2013WR014710.

Yin, Ziyi, Benyou Jia, Shiqiang Wu, Jiangyu Dai, and Deshan Tang. “Comprehensive Forecast of Urban Water-Energy Demand Based on a Neural Network Model,” 2018. https://doi.org/10.3390/w10040385.

Zomer, R. J., A. Trabucco, and S. L. Ustin. “Building Spectral Libraries for Wetlands Land Cover Classification and Hyperspectral Remote Sensing.” *Journal of Environmental Management*, The GlobWetland Symposium: Looking at wetlands from space, 90, no. 7 (May 1, 2009): 2170–77. https://doi.org/10.1016/j.jenvman.2007.06.028.

6
P195 – ENDANGERED AND PROTECTED SPECIES

Overall Commentary on the Literature Review Findings

The search string terms for P195 (detailed in the table below) returned a number of articles about the types of remote sensing technology for data collection on species or habitats (e.g., UAV, LIDAR, camera trap images, acoustic recordings, bio loggers). Some highlights include:

- Pajares (2015) provided a good review of UAV-based applications for wildlife, and Watts et al. (2012) emphasized that UAS had the "potential for revolutionizing natural science observations similar to those transformations that GIS and GPS brought to the community two decades ago."
- An article reviewing 266 wildlife studies using camera trap data (Burton et al., 2015). While the authors were overall supportive of camera trap data, they also noted that "inferences based on detection indices are controversial, and the suitability of alternatives such as occupancy estimation is debatable." The authors called for more transparency in methods and evaluation of studies to lead to more robust inferences from the data.
- Robinson et al. (2010) reviewed biologging technology with regards to bird migration tracking.
- A group of articles in the late 2000s utilized LIDAR and canopy height/heterogeneity as an indicator of biodiversity (see Goetz et al., 2010; Martinuzzi et al., 2009; Vierling et al., 2008; Goetz et al., 2007; and Hyde et al., 2006).

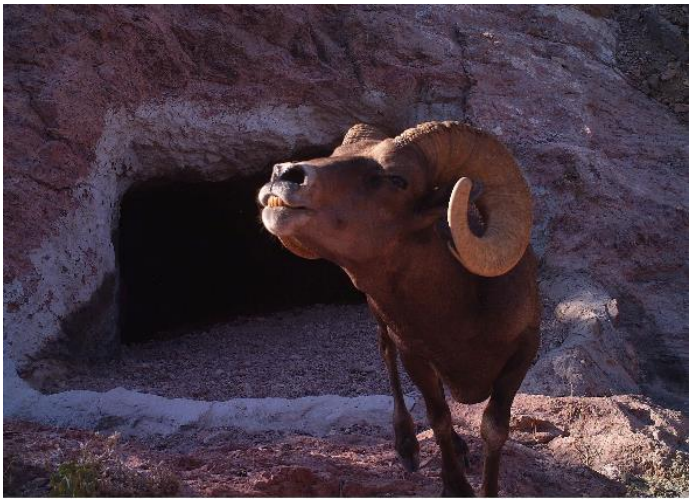

Figure 6-1
'Wildlife selfie' from camera trap (Bighorn sheep, Kofa National Wildlife Refuge, FWS, 2017)

A 2019 *Nature* article provides a good overview of **AI used in both audio and imagery species identification** with multiple examples (Kwok, 2019). In the **audio** realm, Brandes (2008) reviewed avian audio identification at a much more technical level, in terms of hardware and software. Aide et al. (2013) describe an interesting project called ARBIMON (Automated

Remote Biodiversity Monitoring Network) that includes hardware and software for species identification from audio data. The project has an online interface "to help users create machine learning algorithms to automate species identification." *Nature* reported that the site has over 3 million recordings uploaded to help with machine learning classification (Kwok, 2019). Bardeli et al. (2010) tested audio recognition algorithms for detecting "two endangered [EU] bird species and show[ed] how these can be used in automatic habitat mapping." Acevedo et al. (2009) "compared the ability of three machine learning algorithms (linear discriminant analysis, decision tree, and support vector machines) to automate the classification of calls of nine frogs and three bird species." Obrist et al. (2007) discussed challenges in creating a database of bat reference calls for 26 Swiss species.

Figure 6-2
Bat acoustic monitoring station (Missouri River, NPS, 2019)

The search returned fewer articles about species identification from **AI and imagery data** than anticipated. The highlights included Siddiqui et al. (2018), who classified marine fish off the coast of western Australia to 94.3% accuracy from 'typical' underwater video using deep learning methods. Zheng et al. (2017) explained in a highly technical article their use of multi-attention CNN for fine-grained identification of birds (e.g., distinguishing between parts of a bird, and distinguishing between similar birds).

Figure 6-3
Remote cameras can trap a steady stream of images (coyote chasing pronghorn, Sevilleta National Wildlife Refuge, FWS, 2015)

Finally, Dyo et al. (2010) provides lessons from deploying a **wildlife monitoring sensor network** in the UK for badgers. Handcock et al. (2009) also used wireless sensor networks combined with satellite images to track species, with cattle as the case study.

The literature review also returned a few articles on **established methods** such as species distribution modeling (e.g., Maxent modeling, logistic regression and kriging [Philips and Dudik, 2008; Diao and Wang, 2014; Peterson et al., 2007]). Weiers et al. (2004) also reviewed an established GIS-based method for habitat assessment, which, although dated and decidedly not indicative of 'emerging' techniques, provided good introductory information on GIS methods.

Sullivan et al. (2017) reviewed uses of data from the citizen science app eBird for conservation decisions, including regulatory decisions.

In a twist, biodiversity is informing AI, as Karaboga et al. (2014) described in their introduction to an **artificial bee colony (ABC) algorithm** tapping into honey bee 'swarm intelligence.' The uses described in the paper were outside of the environmental field. Of note, however, were multiple uses in the power sector (e.g., in "optimal distributed generation sizing and allocation in distribution systems" and "scheduling in grid environments" [Abu-Mouti and El-Hawary, 2010; Arsuaga-Rios et al., 2011; *in* Karaboga et al., 2014]).

Table 6-1
Search strings for program 195

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR “algorithm” OR "artificial intelligence" OR “remote sensing” OR “machine learning” OR “big data”)	("species conservation" OR "species protection" OR wildlife OR bat OR bird) AND -"bat algorithm"*	46,500	100	34
	(“pollinator” OR “endangered species act” OR “eDNA” OR “species” OR “mitigation”)	73,600	100	5
Articles identified in other program searches				2
Program staff recommended articles				1
Total				**43**
Articles highlighted				**5**

*Initial search results were picking up “bat algorithm” which does not relate to bats or other P195 research areas, so the term was removed in this search string.

Highlighted Literature

Article Title	AI Empowers Conservation Biology (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of multiple uses of AI for species identification from audio and imagery data
Subject Area	Species identification
Program Area	P195
Abstract	“Faced with mountains of image and audio data, researchers are turning to artificial intelligence to answer pressing ecological questions.”
Value Criteria	Reduce costs (of species identification and monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potentially less handling / harm to the species) Provide important new insights (improved accuracy of species identification)
Dataset	NA
Citation	Kwok, Roberta. “AI Empowers Conservation Biology.” Nature 567 (March 4, 2019): 133–34. https://doi.org/10.1038/d41586-019-00746-1.
Additional Information	This resource added by EPRI staff; not part of methodology for this paper. This paper provides a good overview of AI used in audio and imagery species identification.

Article Title	Learning Multi-Attention Convolutional Neural Network for Fine-Grained Image Recognition (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of AI to recognize parts of a species for use in fine-grained species classification
Subject Area	Species identification
Program Area	P195
Abstract	"Proceedings of the IEEE International Conference on Computer Vision"
Value Criteria	Reduce costs (of species identification) Reduce time (reduced labor time) Provide important new insights (improved accuracy of species identification)
Dataset	NA
Citation	Zheng, Heliang, Jianlong Fu, Tao Mei, and Jiebo Luo. "Learning Multi-Attention Convolutional Neural Network for Fine-Grained Image Recognition," 5209–17, 2017. http://openaccess.thecvf.com/content_iccv_2017/html/Zheng_Learning_Multi-Attention_Convolutional_ICCV_2017_paper.html.
Additional Information	Paper covers training AI to recognize parts of a bird (head, wing, etc.), which then can be used for fine-grained classification – distinguishing a Bohemian vs. Cedar waxwing, for example.

Article Title	Real-time Bioacoustics Monitoring and Automated Species Identification (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of machine learning algorithms to identify species from audio data
Subject Area	Species identification
Program Area	P195
Abstract	"Traditionally, animal species diversity and abundance is assessed using a variety of methods that are generally costly, limited in space and time, and most importantly, they rarely include a permanent record. Given the urgency of climate change and the loss of habitat, it is vital that we use new technologies to improve and expand global biodiversity monitoring to thousands of sites around the world. In this article, we describe the acoustical component of the Automated Remote Biodiversity Monitoring Network (ARBIMON), a novel combination of hardware and software for automating data acquisition, data management, and species identification based on audio recordings. The major components of the cyberinfrastructure include: a solar powered remote monitoring station that sends 1-min recordings every 10 min to a base station, which relays the recordings in real-time to the project server, where the recordings are processed and uploaded to the project website (arbimon.net). Along with a module for viewing, listening, and annotating recordings, the website includes a species identification interface to help users create machine learning algorithms to automate species identification. To demonstrate the system we present data on the vocal activity patterns of birds, frogs, insects, and mammals from Puerto Rico and Costa Rica."

Value Criteria	Reduce costs (of species identification) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (new information to improve species management, potentially less handling / harm to the species) Provide important new insights (improved accuracy of species identification, online module aids decision-making)
Dataset	NA
Citation	Aide, T. Mitchell, Carlos Corrada-Bravo, Marconi Campos-Cerqueira, Carlos Milan, Giovany Vega, and Rafael Alvarez. "Real-Time Bioacoustics Monitoring and Automated Species Identification." PeerJ 1 (July 16, 2013): e103. https://doi.org/10.7717/peerj.103.
Additional Information	The Automated Remote Biodiversity Monitoring Network (ARBIMON) is a hardware and software platform for acoustic species identification. The study notes that it has website with "species ID interface to help users create machine learning algorithms to automate species identification." The example provided in the paper is from Puerto Rico.

Article Title	REVIEW: Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of camera traps for species image data collection, and applications of that data, including use of AI for automated species identification
Subject Area	Species identification
Program Area	P195
Abstract	"Reliable assessment of animal populations is a long-standing challenge in wildlife ecology. Technological advances have led to widespread adoption of camera traps (CTs) to survey wildlife distribution, abundance and behavior. As for any wildlife survey method, camera trapping must contend with sources of sampling error such as imperfect detection. Early applications focused on density estimation of naturally marked species, but there is growing interest in broad-scale CT surveys of unmarked populations and communities. Nevertheless, inferences based on detection indices are controversial, and the suitability of alternatives such as occupancy estimation is debatable. We reviewed 266 CT studies published between 2008 and 2013. We recorded study objectives and methodologies, evaluating the consistency of CT protocols and sampling designs, the extent to which CT surveys considered sampling error, and the linkages between analytical assumptions and species ecology. Nearly two-thirds of studies surveyed more than one species, and a majority used response variables that ignored imperfect detection (e.g. presence–absence, relative abundance). Many studies used opportunistic sampling and did not explicitly report details of sampling design and camera deployment that could affect conclusions. Most studies estimating density used capture–recapture methods on marked species, with spatially explicit methods becoming more prominent. Few studies estimated density for unmarked species, focusing instead on occupancy modelling or measures of relative abundance. While occupancy studies estimated detectability, most did not explicitly define key components of the modelling framework (e.g. a site) or discuss potential violations of model assumptions (e.g. site closure). Studies using relative abundance relied on assumptions of equal detectability, and most did not explicitly define expected relationships between measured responses and underlying ecological processes (e.g. animal abundance and movement). Synthesis and applications. The

	rapid adoption of camera traps represents an exciting transition in wildlife survey methodology. We remain optimistic about the technology's promise, but call for more explicit consideration of underlying processes of animal abundance, movement and detection by cameras, including more thorough reporting of methodological details and assumptions. Such transparency will facilitate efforts to evaluate and improve the reliability of camera trap surveys, ultimately leading to stronger inferences and helping to meet modern needs for effective ecological inquiry and biodiversity monitoring."
Value Criteria	Reduce costs (of species identification and monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potentially less handling / harm to the species) Provide important new insights (improved accuracy of species identification)
Dataset	NA
Citation	Burton, A. Cole, Eric Neilson, Dario Moreira, Andrew Ladle, Robin Steenweg, Jason T. Fisher, Erin Bayne, and Stan Boutin. "REVIEW: Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes." Journal of Applied Ecology 52, no. 3 (2015): 675–85. https://doi.org/10.1111/1365-2664.12432.
Additional Information	This is a review article (266 studies) on camera traps.

Article Title	Variability in Echolocation Call Design of 26 Swiss Bat Species: Consequences, Limits and Options for Automated Field Identification with a Synergetic Pattern Recognition Approach (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of audio recognition algorithms to identify bat species; proposal to aggregate audio data as a training dataset
Subject Area	Species identification
Program Area	P195
Abstract	"Pattern recognition algorithms offer a promising approach to recognizing bat species by their echolocation calls. Automated systems like synergetic classifiers may contribute significantly to operator-independent species identification in the field. However, it necessitates the assembling of an appropriate database of reference calls, a task far from trivial. We present data on species specific flexibility in call parameters of all Swiss bat species (except Nyctalus lasiopterus and Plecotus alpinus). The selection of "training-calls" for the classifier is crucial for species identification success. We discuss this in the context of echolocation call variability differing between species and its consequences for the implementation of an automated, species specific bat activity monitoring system."
Value Criteria	Reduce costs (of species identification and monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (potentially less handling / harm to the species) Provide important new insights (improved accuracy of species identification)
Dataset	NA
Citation	Obrist, Martin K., Ruedi Boesch, and Peter F. Flückiger. "Variability in Echolocation

	Call Design of 26 Swiss Bat Species: Consequences, Limits and Options for Automated Field Identification with a Synergetic Pattern Recognition Approach." Mammalia Mamm 68, no. 4 (2007): 307–322. https://doi.org/10.1515/mamm.2004.030.
Additional Information	This study, while a bit dated, discusses assembling a database of bat reference calls, which it notes is difficult. The paper suggests that it could be helpful to pilot/research on acoustic detection of bats.

References

Acevedo, Miguel A., Carlos J. Corrada-Bravo, Héctor Corrada-Bravo, Luis J. Villanueva-Rivera, and T. Mitchell Aide. "Automated Classification of Bird and Amphibian Calls Using Machine Learning: A Comparison of Methods." *Ecological Informatics* 4, no. 4 (September 1, 2009): 206–14. https://doi.org/10.1016/j.ecoinf.2009.06.005.

Aide, T. Mitchell, Carlos Corrada-Bravo, Marconi Campos-Cerqueira, Carlos Milan, Giovany Vega, and Rafael Alvarez. "Real-Time Bioacoustics Monitoring and Automated Species Identification." *PeerJ* 1 (July 16, 2013): e103. https://doi.org/10.7717/peerj.103.

Bardeli, R., D. Wolff, F. Kurth, M. Koch, K. -H. Tauchert, and K. -H. Frommolt. "Detecting Bird Sounds in a Complex Acoustic Environment and Application to Bioacoustic Monitoring." *Pattern Recognition Letters*, Pattern Recognition of Non-Speech Audio, 31, no. 12 (September 1, 2010): 1524–34. https://doi.org/10.1016/j.patrec.2009.09.014.

Brandes, T. Scott. "Automated Sound Recording and Analysis Techniques for Bird Surveys and Conservation." *Bird Conservation International* 18, no. S1 (September 2008): S163–73. https://doi.org/10.1017/S0959270908000415.

Burton, A. Cole, Eric Neilson, Dario Moreira, Andrew Ladle, Robin Steenweg, Jason T. Fisher, Erin Bayne, and Stan Boutin. "REVIEW: Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes." *Journal of Applied Ecology* 52, no. 3 (2015): 675–85. https://doi.org/10.1111/1365-2664.12432.

Diao, Chunyuan, and Le Wang. "Development of an Invasive Species Distribution Model with Fine-Resolution Remote Sensing." *International Journal of Applied Earth Observation and Geoinformation* 30 (August 1, 2014): 65–75. https://doi.org/10.1016/j.jag.2014.01.015.

Dyo, Vladimir, Stephen A. Ellwood, David W. Macdonald, Andrew Markham, Cecilia Mascolo, Bence Pásztor, Salvatore Scellato, Niki Trigoni, Ricklef Wohlers, and Kharsim Yousef. "Evolution and Sustainability of a Wildlife Monitoring Sensor Network." In *Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems*, 127–140. SenSys '10. New York, NY, USA: ACM, 2010. https://doi.org/10.1145/1869983.1869997.

Goetz, Scott J., Daniel Steinberg, Matthew G. Betts, Richard T. Holmes, Patrick J. Doran, Ralph Dubayah, and Michelle Hofton. "Lidar Remote Sensing Variables Predict Breeding Habitat of a Neotropical Migrant Bird." *Ecology* 91, no. 6 (2010): 1569–76. https://doi.org/10.1890/09-1670.1.

Goetz, Scott, Daniel Steinberg, Ralph Dubayah, and Bryan Blair. "Laser Remote Sensing of Canopy Habitat Heterogeneity as a Predictor of Bird Species Richness in an Eastern Temperate

Forest, USA." *Remote Sensing of Environment* 108, no. 3 (June 15, 2007): 254–63. https://doi.org/10.1016/j.rse.2006.11.016.

Hyde, Peter, Ralph Dubayah, Wayne Walker, J. Bryan Blair, Michelle Hofton, and Carolyn Hunsaker. "Mapping Forest Structure for Wildlife Habitat Analysis Using Multi-Sensor (LiDAR, SAR/InSAR, ETM+, Quickbird) Synergy." *Remote Sensing of Environment* 102, no. 1 (May 30, 2006): 63–73. https://doi.org/10.1016/j.rse.2006.01.021.

Karaboga, Dervis, Beyza Gorkemli, Celal Ozturk, and Nurhan Karaboga. "A Comprehensive Survey: Artificial Bee Colony (ABC) Algorithm and Applications." *Artificial Intelligence Review* 42, no. 1 (June 1, 2014): 21–57. https://doi.org/10.1007/s10462-012-9328-0.

Kwok, Roberta. "AI Empowers Conservation Biology." *Nature* 567 (March 4, 2019): 133–34. https://doi.org/10.1038/d41586-019-00746-1.

Martinuzzi, Sebastián, Lee A. Vierling, William A. Gould, Michael J. Falkowski, Jeffrey S. Evans, Andrew T. Hudak, and Kerri T. Vierling. "Mapping Snags and Understory Shrubs for a LiDAR-Based Assessment of Wildlife Habitat Suitability." *Remote Sensing of Environment* 113, no. 12 (December 15, 2009): 2533–46. https://doi.org/10.1016/j.rse.2009.07.002.

Obrist, Martin K., Ruedi Boesch, and Peter F. Flückiger. "Variability in Echolocation Call Design of 26 Swiss Bat Species: Consequences, Limits and Options for Automated Field Identification with a Synergetic Pattern Recognition Approach." *Mammalia Mamm* 68, no. 4 (2007): 307–322. https://doi.org/10.1515/mamm.2004.030.

Pajares, Gonzalo. "Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs)." *Photogrammetric Engineering & Remote Sensing* 81, no. 4 (April 1, 2015): 281–330. https://doi.org/10.14358/PERS.81.4.281.

Peterson, A. Townsend, Monica Papeş, and Muir Eaton. "Transferability and Model Evaluation in Ecological Niche Modeling: A Comparison of GARP and Maxent." *Ecography* 30, no. 4 (2007): 550–60. https://doi.org/10.1111/j.0906-7590.2007.05102.x.

Phillips, Steven J., and Miroslav Dudík. "Modeling of Species Distributions with Maxent: New Extensions and a Comprehensive Evaluation." *Ecography* 31, no. 2 (2008): 161–75. https://doi.org/10.1111/j.0906-7590.2008.5203.x.

Robinson, W. Douglas, Melissa S. Bowlin, Isabelle Bisson, Judy Shamoun-Baranes, Kasper Thorup, Robert H. Diehl, Thomas H. Kunz, Sarah Mabey, and David W. Winkler. "Integrating Concepts and Technologies to Advance the Study of Bird Migration." *Frontiers in Ecology and the Environment* 8, no. 7 (2010): 354–61. https://doi.org/10.1890/080179.

Siddiqui, Shoaib Ahmed, Ahmad Salman, Muhammad Imran Malik, Faisal Shafait, Ajmal Mian, Mark R. Shortis, and Euan S. Harvey. "Automatic Fish Species Classification in Underwater Videos: Exploiting Pre-Trained Deep Neural Network Models to Compensate for Limited Labelled Data." *ICES Journal of Marine Science* 75, no. 1 (January 1, 2018): 374–89. https://doi.org/10.1093/icesjms/fsx109.

Sullivan, Brian L., Tina Phillips, Ashley A. Dayer, Christopher L. Wood, Andrew Farnsworth, Marshall J. Iliff, Ian J. Davies, et al. "Using Open Access Observational Data for Conservation

Action: A Case Study for Birds." *Biological Conservation*, The role of citizen science in biological conservation, 208 (April 1, 2017): 5–14. https://doi.org/10.1016/j.biocon.2016.04.031.

Vierling, Kerri T., Lee A. Vierling, William A. Gould, Sebastian Martinuzzi, and Rick M. Clawges. "Lidar: Shedding New Light on Habitat Characterization and Modeling." *Frontiers in Ecology and the Environment* 6, no. 2 (2008): 90–98. https://doi.org/10.1890/070001.

Watts, Adam C., Vincent G. Ambrosia, and Everett A. Hinkley. "Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use." *Remote Sensing* 4, no. 6 (June 2012): 1671–92. https://doi.org/10.3390/rs4061671.

Weiers, Stefan, Michael Bock, Michael Wissen, and Godela Rossner. "Mapping and Indicator Approaches for the Assessment of Habitats at Different Scales Using Remote Sensing and GIS Methods." *Landscape and Urban Planning*, Development of European Landscapes, 67, no. 1 (March 15, 2004): 43–65. https://doi.org/10.1016/S0169-2046(03)00028-8.

Zheng, Heliang, Jianlong Fu, Tao Mei, and Jiebo Luo. "Learning Multi-Attention Convolutional Neural Network for Fine-Grained Image Recognition," 5209–17, 2017. http://openaccess.thecvf.com/content_iccv_2017/html/Zheng_Learning_Multi-Attention_Convolutional_ICCV_2017_paper.html.

7
P196 – WATER QUALITY

Overall Commentary on the Literature Review Findings

The search string terms for P196 (detailed in the table below) identified a number of articles about remote sensing and water quality parameters predicted by models and/or AI. A fair number of articles used satellite-collected imagery, including hyperspectral and thermal data. Those new to this research area may appreciate Governder et al. (2007), who detailed "the differences between multispectral and hyperspectral data; [and] spatial and spectral resolutions."

Chang et al. (2017) broadly summed major themes encountered in the satellite-focused research results:

> "…since the 2000s, the remote sensing community has been experiencing a regime shift to create scientific quality remote sensing data encompassing measurements from multiple satellite missions via data fusion or merging on one hand (Fargion and McClain, 2002), and to conduct intelligent feature extraction with the aid of machine learning or data mining algorithms on the other hand (Chang et al., 2009, 2012, 2013)."

Chang et al. (2017) is a good example of the use of **satellite-based ocean color reflectance** for an AI-enabled estimation of nutrients, chlorophyll-a, dissolved oxygen, and suspended sediments in Lake Nicaragua. Olmanson et al. (2015) described advances in the ability to monitor water quality parameters in lakes in Minnesota, comparing abilities and outcomes based on imagery from the Landsat satellite to newer MERIS satellite imagery and upcoming satellite missions (Landsat 8 and Sentinel-2). Chebud et al. (2012) described monitoring sediment, phosphorous and chlorophyll-a using remote sensing and ANN in the Everglades. Several articles used ocean color reflectance data to identify **harmful algal blooms** (HABs), including use of algorithms for chlorophyll-a or Trichodesmium remote sensing (Stumpf and Tomlinson, 2008; McKinna, 2015).

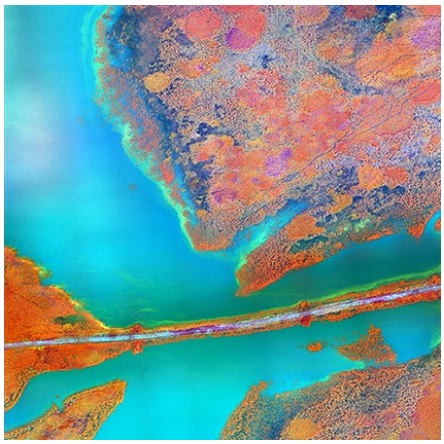

Figure 7-1
Drone-based multispectral imagery identifies HABs (Milford Lake KS, USGS, 2016)

Zang et al. (2012) used UAVs to monitor sediment pollution in China. Multiple articles delved deeply into technical aspects of satellite data, for example of merging multiple satellite imaging data sources (including use of AI) and creating cloud-free data (Pahlevan et al., 2017; Chang, 2017).

Although not an application of emerging technology or data science, Shaeffer et al. (2013) investigated **EPA staff perceptions of using satellite data** for remote water quality monitoring. None of the staff surveyed had personally used satellite data, but half indicated they knew of a colleague who was doing so. The following factors were identified as potential barriers to using satellite data: "Reliability, Cloudy days, Spatial resolution, Cost, Data processing, Availability of the technology, Divide between technical staff and management, Fully trained staff, Lack of understanding about the technology, [and] Data storage." It is important to note that the results of this study may be outdated, as many of these challenges have been or are currently being addressed. Several articles identified opportunities related to **thermal water monitoring**. Wu et al. (2007) monitored thermal discharge of a nuclear plant in China using "Therm-infrared bands" data. Piotrowski et al. (2015) compared multiple neural network methods for modeling stream temperature and interestingly found that "simple and popular multi-layer perceptron neural networks are in most cases not outperformed by more complex and advanced models." They noted: "This may be a warning for anyone who wish to promote their own models, that their superiority should be verified in different ways." Despini and Teggi (2013) used a new algorithm (Sharpening Water Thermal Imagery) to improve resolution of thermal and reflectivity satellite data for monitoring the thermal profile of coastal areas in Italy for compliance purposes.

Several articles utilized **reflectance data to identify heavy metals** in soils – most using lab-based reflectance spectroscopy, which resembles a soil photo shoot (Maliki et al., 2012; Shi et al., 2014; Melendez-Pastor et al., 2011; Wang et al., 2018). The search strings only identified one article which used satellite-derived hyperspectral data to identify heavy metal pollution *in water* (iron, zinc, copper, chromium, lead and cadmium) at a 1km-resolution scale (Swain and Sahoo, 2017). One additional study focused on lead, zinc and arsenic contamination in stream sediments using hyperspectral data and spectroscopy (Choe et al., 2008).

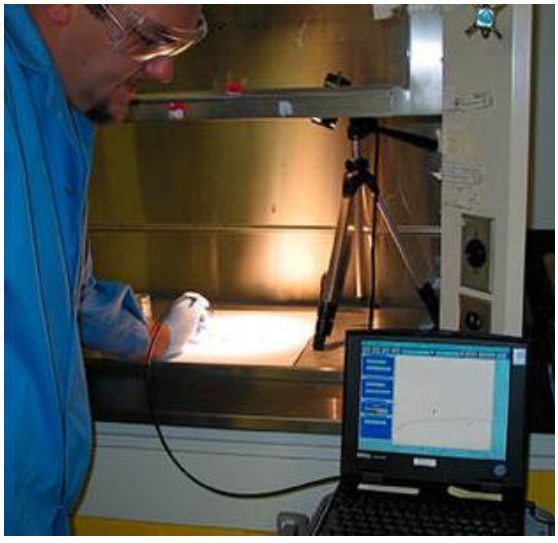

Figure 7-2
Reflectance spectroscopy (USGS, 2017)

The literature search identified a number of **review articles** that are useful in synthesizing information in specific areas: estimating water quality parameters from remote sensing generally (Hajigholizadeh et al., 2016), integration of AI into water quality modelling (Chau, 2006), hyperspectral imagery for water resources (Governder et al., 2007), analyzing coastal water quality from satellite imagery using multiple techniques (Bierman et al., 2011; who highlight "a sample dataset of MODIS chlorophyll-a imagery"), remote sensing for lake research and monitoring (Palmer et al., 2015; Dornhofer and Oppelt, 2016), and a discussion of low cost water quality pollution sensors (Radu et al., 2010).

Finally, one **broad comment** from Budka et al. (2010) was a critique that "The environmental scientists often try to apply various machine learning techniques to their data without much success, mostly because of the lack of experience with different methods and required 'under the hood' knowledge."

Table 7-1
Search strings for program 196

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "algorithm" OR "artificial intelligence" OR "remote sensing" OR "machine learning" OR "big data")	("mercury" OR "bromide" OR "water quality monitoring" OR "nutrients" OR "disinfection by products" OR "wastewater")	16,700	100	6
	("stormwater" OR "water quality" "effluent" OR "limnology" OR "arsenic" OR "power plant discharge")	24,000	200	16
	("nutrient runoff" OR "contaminants" OR "water pollution")	16,600	100	4
	("thermal water pollution" OR "industrial water pollution")	150	100	5
	("heavy metals" OR "arsenic" OR "selenium" OR "harmful aquatic bloom")	18,000	100	9
	("water quality" AND "ocean color reflectance")	30	30	9
Program staff recommended articles				1
Total				**50**
Articles highlighted				**5**

Highlighted Literature

Article Title	A Comprehensive Review on Water Quality Parameters Estimation Using Remote Sensing Techniques (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of emerging data collection technologies (spaceborne and airborne sensors) of multiple types of data (imagery, hyperspectral imagery, other) and approaches to evaluate water quality of multiple parameters
Subject Area	Water quality
Program Area	P196
Abstract	"Remotely sensed data can reinforce the abilities of water resources researchers and decision makers to monitor waterbodies more effectively. Remote sensing techniques have been widely used to measure the qualitative parameters of waterbodies (i.e., suspended sediments, colored dissolved organic matter (CDOM), chlorophyll-a, and pollutants). A large number of different sensors on board various satellites and other platforms, such as airplanes, are currently used to measure the amount of radiation at different wavelengths reflected from the water's surface. In this review paper, various properties (spectral, spatial and temporal, etc.) of the more commonly employed spaceborne and airborne sensors are tabulated to be used as a sensor selection guide. Furthermore, this paper investigates the commonly used approaches and sensors employed in evaluating and quantifying the eleven water quality parameters. The parameters include: chlorophyll-a (chl-a), colored dissolved organic matters (CDOM), Secchi disk depth (SDD), turbidity, total suspended sediments (TSS), water temperature (WT), total phosphorus (TP), sea surface salinity (SSS), dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD)."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time / field sampling) Improve environmental, health, or safety outcomes (potential safety improvements) Provide important new insights (potential identification of operational risk)
Dataset	NA
Citation	Hajigholizadeh, Mohammad, Assefa Melesse, and Lakshmi Reddi. "(PDF) A Comprehensive Review on Water Quality Parameters Estimation Using Remote Sensing Techniques." *Sensors* 16, no. 8 (September 2016). https://doi.org/10.3390/s16081298.
Additional Information	This is a review article on remote sensing and water quality.

Article Title	Integrating Multisensor Satellite Data Merging and Image Reconstruction in Support of Machine Learning for Better Water Quality Management (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of algorithms and machine learning to estimate water quality from satellite-based ocean color reflectance data
Subject Area	Water quality
Program Area	P196
Abstract	"Monitoring water quality changes in lakes, reservoirs, estuaries, and coastal waters is critical in response to the needs for sustainable development. This study develops a remote sensing-based multiscale modeling system by integrating multi-sensor

	satellite data merging and image reconstruction algorithms in support of feature extraction with machine learning leading to automate continuous water quality monitoring in environmentally sensitive regions. This new Earth observation platform, termed "cross-mission data merging and image reconstruction with machine learning" (CDMIM), is capable of merging multiple satellite imageries to provide daily water quality monitoring through a series of image processing, enhancement, reconstruction, and data mining/machine learning techniques. Two existing key algorithms, including Spectral Information Adaptation and Synthesis Scheme (SIASS) and SMart Information Reconstruction (SMIR), are highlighted to support feature extraction and content-based mapping. Whereas SIASS can support various data merging efforts to merge images collected from cross-mission satellite sensors, SMIR can overcome data gaps by reconstructing the information of value-missing pixels due to impacts such as cloud obstruction. Practical implementation of CDMIM was assessed by predicting the water quality over seasons in terms of the concentrations of nutrients and chlorophyll-a, as well as water clarity in Lake Nicaragua, providing synergistic efforts to better monitor the aquatic environment and offer insightful lake watershed management strategies."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time / field sampling) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA
Citation	Chang, Ni-Bin, Kaixu Bai, and Chi-Farn Chen. "Integrating Multisensor Satellite Data Merging and Image Reconstruction in Support of Machine Learning for Better Water Quality Management." Journal of Environmental Management 201 (October 1, 2017): 227–40. https://doi.org/10.1016/j.jenvman.2017.06.045.
Additional Information	This paper is a good example of using ocean color reflectance, with an example application on Lake Nicaragua.

Article Title	Low Cost, Calibration-Free Sensors for in Situ Determination of Natural Water Pollution (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Demonstration of new water quality sensor technology
Subject Area	Water quality
Program Area	P196
Abstract	"One of the critical challenges for analytical sciences is the ability to perform reliable environmental monitoring at remote locations while significantly reducing per-sample and per-measurement cost. In this work, we demonstrate an approach that demonstrates production of ultra-sensitive sensors with almost identical response characteristics on a mass scale, their integration with low-cost electronics for wireless data transmission and the use of such devices in environmental analysis."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time / field sampling) Improve environmental, health, or safety outcomes (potential safety improvements)
Dataset	NA
Citation	Radu, A., S. Anastasova, C. Fay, D. Diamond, J. Bobacka, and A. Lewenstam. "Low Cost, Calibration-Free Sensors for in Situ Determination of Natural Water Pollution."

	In *2010 IEEE SENSORS*, 1487–90, 2010. https://doi.org/10.1109/ICSENS.2010.5690357.
Additional Information	NA

Article Title	Mapping of Heavy Metal Pollution in River Water at Daily Time-Scale Using Spatio-Temporal Fusion of MODIS-Aqua and Landsat Satellite Imageries (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Uses regression analysis and genetic algorithm to estimate heavy metal pollution at a coarse scale using satellite data
Subject Area	Water quality – heavy metals
Program Area	P196
Abstract	"For river water quality monitoring at 30m × 1-day spatio-temporal scales, a spatial and temporal adaptive reflectance fusion model (STARFM) is developed for estimating turbidity (Tu), total suspended solid (TSS), and six heavy metals (HV) of iron, zinc, copper, chromium, lead and cadmium, by blending the Moderate-Resolution Imaging Spectroradiometer (MODIS) and Landsat (Ls) spectral bands. A combination of regression analysis and genetic algorithm (GA) techniques are applied to develop spectral relationships between Tu-Ls, TSS-Tu, and each HV-TSS. The STARFM algorithm and all the developed relationship models are evaluated satisfactorily by various performance evaluation measures to develop heavy metal pollution index-based vulnerability maps at 1-km resolution in the Brahmani River in eastern India. The Monte-Carlo simulation based analysis of the developed formulations reveals that the uncertainty in estimating Zn and Cd is the minimum (1.04%) and the maximum (5.05%), respectively. Hence, the remote sensing based approach developed herein can effectively be used in many world rivers for real-time monitoring of heavy metal pollution."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time / field sampling) Provide important new insights (new estimates in unmonitored areas such as developing countries)
Dataset	NA
Citation	Swain, Ratnakar, and Bhabagrahi Sahoo. "Mapping of Heavy Metal Pollution in River Water at Daily Time-Scale Using Spatio-Temporal Fusion of MODIS-Aqua and Landsat Satellite Imageries." Journal of Environmental Management 192 (May 1, 2017): 1–14. https://doi.org/10.1016/j.jenvman.2017.01.034.
Additional Information	This paper uses MODIS and Landsat spectral data with regression analysis and genetic algorithm at a low resolution (1km) for heavy metal monitoring in India. The paper concludes that "…the remote sensing based approach developed herein can effectively be used in many world rivers for real-time monitoring of heavy metal pollution."

Article Title	Remote Sensing of Harmful Algal Blooms (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of uses of remote sensing and analysis (including use of algorithms) to detect harmful algal blooms
Subject Area	Water quality – harmful algal blooms
Program Area	P196
Abstract	"Monitoring and providing early warning for toxic HABs is critical for protecting public health, wild and farmed fish and shellfish, and endangered species (such as marine mammals). Current monitoring efforts are done by measuring the concentration of toxic cells in the water and toxin levels in shellfish tissue. As these efforts are logistically demanding and labor intensive, methods which improve the efficiency of field data collection are considered essential. Accordingly, HAB monitoring programs have an intense interest in remote sensing as a tool to detect and provide the location and extent of HABs, in real-time. This chapter discusses the current and potential uses of remote sensing for HAB monitoring efforts."
Value Criteria	Reduce costs (of monitoring) Reduce time (reduced labor time) Improve environmental, health, or safety outcomes (method has less harm to species) Provide important new insights (near real time information, potential identification of operational risk)
Dataset	NA
Citation	Stumpf, Richard, and Michelle Tomlinson. "Remote Sensing of Harmful Algal Blooms." In Remote Sensing of Coastal Aquatic Environments, 277–96, 2008. https://doi.org/10.1007/978-1-4020-3100-7_12.
Additional Information	While a bit dated, this paper provides a thorough review of remote sensing of HABs. A number of approaches are reviewed, including use of "one of several standard remote sensing chlorophyll algorithms" or an algorithm "developed for a species-specific algal bloom [such as] Trichodesmium."

References

Bierman, Paul, Megan Lewis, Bertram Ostendorf, and Jason Tanner. "A Review of Methods for Analysing Spatial and Temporal Patterns in Coastal Water Quality." *Ecological Indicators*, Spatial information and indicators for sustainable management of natural resources, 11, no. 1 (January 1, 2011): 103–14. https://doi.org/10.1016/j.ecolind.2009.11.001.

Budka, Marcin, Bogdan Gabrys, and Elisa Ravagnan. "Robust Predictive Modelling of Water Pollution Using Biomarker Data." *Water Research* 44, no. 10 (May 1, 2010): 3294–3308. https://doi.org/10.1016/j.watres.2010.03.006.

Chang, Ni-Bin, Kaixu Bai, and Chi-Farn Chen. "Integrating Multisensor Satellite Data Merging and Image Reconstruction in Support of Machine Learning for Better Water Quality Management." *Journal of Environmental Management* 201 (October 1, 2017): 227–40. https://doi.org/10.1016/j.jenvman.2017.06.045.

Chau, Kwok-wing. "A Review on Integration of Artificial Intelligence into Water Quality Modelling." *Marine Pollution Bulletin* 52, no. 7 (July 1, 2006): 726–33. https://doi.org/10.1016/j.marpolbul.2006.04.003.

Chebud, Yirgalem, Ghinwa M. Naja, Rosanna G. Rivero, and Assefa M. Melesse. "Water Quality Monitoring Using Remote Sensing and an Artificial Neural Network." *Water, Air, & Soil Pollution* 223, no. 8 (October 1, 2012): 4875–87. https://doi.org/10.1007/s11270-012-1243-0.

Choe, Eunyoung, Freek van der Meer, Frank van Ruitenbeek, Harald van der Werff, Boudewijn de Smeth, and Kyoung-Woong Kim. "Mapping of Heavy Metal Pollution in Stream Sediments Using Combined Geochemistry, Field Spectroscopy, and Hyperspectral Remote Sensing: A Case Study of the Rodalquilar Mining Area, SE Spain." *Remote Sensing of Environment* 112, no. 7 (July 15, 2008): 3222–33. https://doi.org/10.1016/j.rse.2008.03.017.

Despini, Francesca, and Sergio Teggi. "Analysis of Temperature Maps of Waterbodies Obtained from ASTER TIR Images." *International Journal of Remote Sensing* 34, no. 9–10 (May 1, 2013): 3636–53. https://doi.org/10.1080/01431161.2012.716544.

Dörnhöfer, Katja, and Natascha Oppelt. "Remote Sensing for Lake Research and Monitoring – Recent Advances." *Ecological Indicators* 64 (May 1, 2016): 105–22. https://doi.org/10.1016/j.ecolind.2015.12.009.

Govender, M., K. Chetty, and H. Bulcock. "A Review of Hyperspectral Remote Sensing and Its Application in Vegetation and Water Resource Studies." *Water SA* 33, no. 2 (January 1, 2007). https://doi.org/10.4314/wsa.v33i2.49049.

Hajigholizadeh, Mohammad, Assefa Melesse, and Lakshmi Reddi. "A Comprehensive Review on Water Quality Parameters Estimation Using Remote Sensing Techniques." *Sensors* 16, no. 8 (September 2016). https://doi.org/10.3390/s16081298.

Maliki, A. A., G. Owens, and D. Bruce. "CAPABILITIES OF REMOTE SENSING HYPERSPECTRAL IMAGES FOR THE DETECTION OF LEAD CONTAMINATION: A REVIEW." In *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, I–7:55–60. Copernicus GmbH, 2012. https://doi.org/10.5194/isprsannals-I-7-55-2012.

McKinna, Lachlan I. W. "Three Decades of Ocean-Color Remote-Sensing Trichodesmium Spp. in the World's Oceans: A Review." *Progress in Oceanography* 131 (February 1, 2015): 177–99. https://doi.org/10.1016/j.pocean.2014.12.013.

Melendez-Pastor, Ignacio, Jose Navarro-Pedreño, Ignacio Gómez Lucas, and M Almendro-Candel. "The Use of Remote Sensing to Locate Heavy Metal as Source of Pollution." In *Advances in Environmental Research*, 225–33, 2011.

Olmanson, Leif G., Patrick L. Brezonik, and Marvin E. Bauer. "Remote Sensing for Regional Lake Water Quality Assessment: Capabilities and Limitations of Current and Upcoming Satellite Systems." In *Advances in Watershed Science and Assessment*, edited by Tamim Younos and Tammy E. Parece, 111–40. The Handbook of Environmental Chemistry. Cham: Springer International Publishing, 2015. https://doi.org/10.1007/978-3-319-14212-8_5.

Pahlevan, N., B. Smith, C. Binding, and D. M. O'Donnell. "Spectral Band Adjustments for Remote Sensing Reflectance Spectra in Coastal/Inland Waters." *Optics Express* 25, no. 23 (November 13, 2017): 28650–67. https://doi.org/10.1364/OE.25.028650.

Palmer, Stephanie C. J., Tiit Kutser, and Peter D. Hunter. "Remote Sensing of Inland Waters: Challenges, Progress and Future Directions." *Remote Sensing of Environment*, Special Issue: Remote Sensing of Inland Waters, 157 (February 1, 2015): 1–8. https://doi.org/10.1016/j.rse.2014.09.021.

Piotrowski, Adam P., Maciej J. Napiorkowski, Jaroslaw J. Napiorkowski, and Marzena Osuch. "Comparing Various Artificial Neural Network Types for Water Temperature Prediction in Rivers." *Journal of Hydrology* 529 (October 1, 2015): 302–15. https://doi.org/10.1016/j.jhydrol.2015.07.044.

Radu, A., S. Anastasova, C. Fay, D. Diamond, J. Bobacka, and A. Lewenstam. "Low Cost, Calibration-Free Sensors for in Situ Determination of Natural Water Pollution." In *2010 IEEE SENSORS*, 1487–90, 2010. https://doi.org/10.1109/ICSENS.2010.5690357.

Schaeffer, Blake A., Kelly G. Schaeffer, Darryl Keith, Ross S. Lunetta, Robyn Conmy, and Richard W. Gould. "Barriers to Adopting Satellite Remote Sensing for Water Quality Management." *International Journal of Remote Sensing* 34, no. 21 (November 10, 2013): 7534–44. https://doi.org/10.1080/01431161.2013.823524.

Shi, Tiezhu, Yiyun Chen, Yaolin Liu, and Guofeng Wu. "Visible and Near-Infrared Reflectance Spectroscopy—An Alternative for Monitoring Soil Contamination by Heavy Metals." *Journal of Hazardous Materials* 265 (January 30, 2014): 166–76. https://doi.org/10.1016/j.jhazmat.2013.11.059.

Stumpf, Richard, and Michelle Tomlinson. "Remote Sensing of Harmful Algal Blooms." In *Remote Sensing of Coastal Aquatic Environments*, 277–96, 2008. https://doi.org/10.1007/978-1-4020-3100-7_12.

Swain, Ratnakar, and Bhabagrahi Sahoo. "Mapping of Heavy Metal Pollution in River Water at Daily Time-Scale Using Spatio-Temporal Fusion of MODIS-Aqua and Landsat Satellite Imageries." *Journal of Environmental Management* 192 (May 1, 2017): 1–14. https://doi.org/10.1016/j.jenvman.2017.01.034.

Wang, Fenghe, Jay Gao, and Yong Zha. "Hyperspectral Sensing of Heavy Metals in Soil and Vegetation: Feasibility and Challenges." *ISPRS Journal of Photogrammetry and Remote Sensing* 136 (February 1, 2018): 73–84. https://doi.org/10.1016/j.isprsjprs.2017.12.003.

Wu, C., Q. Wang, Z. Yang, and W. Wang. "Monitoring Heated Water Pollution of the DaYaWan Nuclear Power Plant Using TM Images." *International Journal of Remote Sensing* 28, no. 5 (March 1, 2007): 885–90. https://doi.org/10.1080/01431160600580616.

Zang, W., J. Lin, Y. Wang, and H. Tao. "Investigating Small-Scale Water Pollution with UAV Remote Sensing Technology." In *World Automation Congress 2012*, 1–4, 2012.

8
P201 – ENERGY, ENVIRONMENTAL, AND CLIMATE POLICY ANALYSIS

Overall Commentary on the Literature Review Findings

Even after refining search strings with program manager input, the search returns for this program were largely more relevant to non-EH&S research. For example, there were multiple papers applying AI to smart grid management or prediction of renewable generation, which though relevant to the electric power sector, were areas more relevant to generation or transmission and distribution-focused research. These findings were echoed by Li et al. (2019), who provided a very insightful literature review of the use of big data in energy economy modeling and noted:

> "There is clear evidence therefore, that big data platforms and concepts have already begun to be applied in various sub-domains of the energy system [e.g., energy efficient computing, energy performance of buildings, and big data in the context of "smart" cities and urban energy planning]. However, our 200+ paper review finds that the application of modern data science specifically to energy economy modelling and the implications for strategic decision making on energy and climate mitigation policy remain entirely unexplored."

One large data set identified in Lit et al.'s (2019) literature review was the **Building Performance Database** used by Chang and Han (2019). The data "stores the building performance data for more than 1 million buildings in the U.S." and was used by the authors to review the trends of energy efficiency of buildings in the U.S. in total, by state, by category such as education, and over time.

Our own search returned three publications on **energy modelling**, two of which used 'standard' modelling: Cohen and Caron, 2018, using a hybrid model linking a computable general equilibrium model of the economy to the Regional Energy Deployment System; and Victor et al., 2018, using the MARKAL nine-region model. The third paper, Kialashaki and Reisel (2014), found superiority of an ANN method to multi-linear regression modeling of energy demand in the industrial sector in the U.S. The authors conclude: "This study suggests that the ANN technique is a reliable and powerful technique which can effectively perform input/output mapping." The paper also nicely summarizes the history of use of regression models and ANN in energy demand modeling, which appeared to be focused on nations with high population growth predictions – especially Turkey (the authors summarize six papers focused on the country). In Turkey, the following forms of AI were applied with success over traditional models: ANN, grey prediction with rolling mechanism, ant colony optimization, particle swarm optimization, and fuzzy logic. The authors also published a similar paper but focused on energy demand of the residential sector (Kialashaki and Reisel, 2014).

Table 8-1
Search strings for program 201

Note: The first two sets of program area terms were unsuccessful, so we refined the terms with help of the program manager and ran searches iteratively to identify relevant papers.

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "artificial intelligence" OR "remote sensing" OR "machine learning" OR "big data")	("energy policy" OR "environmental policy" OR "climate policy" OR "environmental regulation" OR "clean energy")	17,000	200	3
	("air quality standards" OR "climate change" OR "decarbonization" OR "environmental standards")	19,400	200	1
	("decarbonization" OR "economic impacts of decarbonization" OR "decarbonization cost")	2,170	100	1
	("electrification" OR "emerging energy technologies" OR "renewable energy")	16,600	100	6
	("economic impacts" AND "decarbonization")	1,610	200	3
	("decarbonization")	2,180	100	5
	("cost" AND "decarbonization")	1,290	100	2
Total				**21**
Articles highlighted				**4**

Highlighted Literature

Article Title	Development and Validation of Artificial Neural Network Models of the Energy Demand in the Industrial Sector of the United States (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of ANN in a US industrial energy demand model
Subject Area	Energy demand modeling
Program Area	P201
Abstract	"In the United States, the industrial sector is the driving engine of economic development, and energy consumption in this sector may be considered as the fuel for this engine. In order to keep this sector sustainable (diverse and productive over the time), energy planning should be carried out comprehensively and precisely. This paper describes the development of two types of numerical energy models which are able to predict the United States' future industrial energy-demand. One model uses an ANN (artificial neural network) technique, and the other model uses a MLR (multiple linear regression) technique. Various independent variables (GDP, price of energy carriers) are tested. The future industrial energy demand can then be forecasted based on a defined scenario. The ANN model anticipates a 16% increase in energy demand from 2012 by 2030. In this forecast, the model assumes that the effective independent parameters remain constant during this period and only GDP grows with a second-

	order polynomial trend. The forecast result, which shows consistency with published predictions, may be considered as an indication of the need for development of new and low-cost energy sources. This study suggests that the ANN technique is a reliable and powerful technique which can effectively perform input/output mapping. In order to validate the performance of the models, the results of the ANN model is compared to the projections from the Energy Information Administration of the U.S. Department of Energy."
Value Criteria	Provide important new insights (potential for improved model/simulation accuracy, new information for energy modeling)
Dataset	NA
Citation	Kialashaki, Arash, and John R. Reisel. "Development and Validation of Artificial Neural Network Models of the Energy Demand in the Industrial Sector of the United States." Energy 76 (November 1, 2014): 749–60. https://doi.org/10.1016/j.energy.2014.08.072.
Additional Information	This paper develops/tests an ANN technique in a US industrial energy demand model, which compares well to US EIA/DOE projections.

Article Title	Is the U.S. Building Sector on a Low-Carbon Transition Trajectory? - Evidence from Building Performance Big Data (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of big data in energy demand modeling
Subject Area	Energy demand modeling
Program Area	P201
Abstract	"Nearly one-third of total energy consumption is attributed to the building sector in the U.S, which also accounts for around 40% of CO2 emissions. The decarbonization of the U.S. economy, like other countries, largely depends on the low-carbon transition of the building sector. However, while most studies focus on the technical and economic aspects of decarbonizing buildings such as the studies on deep energy retrofits at the individual building level, little is known in terms of whether the U.S. building sector in the past is on a low-carbon transition trajectory from a whole sector perspective. To respond to this gap of knowledge, this study examined the building performance big data from the Building Performance Database (BPD) which stores the building performance data for more than 1 million buildings in the U.S. The results indicate that different sub-sectors experience different levels of decarbonization. For instance, the education building sector does not experience obvious energy efficiency improvements over the past 100 years, while the single-family house stock has shown an obvious energy efficiency improvement from 2000. Buildings in different states also show different decarbonization trend. For instance, the electric energy use intensity (electric EUI) of single-family houses in California and Florida has shown a very steady decrease since 1950, while Virginia does not show this trend in this aspect. This study demonstrates the spatial-temporal complexity of low-carbon transitions of the building sector in the U.S. Policies needs to be formulated to facilitate low-carbon transitions of building sectors considering this complexity."
Value Criteria	Provide important new insights (new information for energy modeling)
Dataset	Building Performance Database
Citation	Chang, Ruidong, and Yilong Han. "Is the U.S. Building Sector on a Low-Carbon

	Transition Trajectory? - Evidence from Building Performance Big Data." SSRN Scholarly Paper. Rochester, NY: Social Science Research Network, June 5, 2019. https://papers.ssrn.com/abstract=3399333.
Additional Information	This resource added by EPRI staff; not part of official methodology. This study uses "the Building Performance Database (BPD) which stores the building performance data for more than 1 million buildings in the U.S. to assess the trajectory of energy efficiency/decarbonization of buildings in the US both in total and by category (e.g., education), and geographically and temporally.

Article Title	Modeling of the energy demand of the residential sector in the United States using regression models and artificial neural networks (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of ANN in a US industrial energy demand model
Subject Area	Energy demand modeling
Program Area	P201
Abstract	"This paper describes the development of energy-demand models which are able to predict the future energy demand in the residential sector of the United States. One set of models use an artificial neural network (ANN) technique, and the other set of models use a multiple linear regression (MLR) technique. The models are used to forecast future household energy demand considering different scenarios for the growth rates of the effective factors in the models. The household sector includes all energy-consuming activities in residential units (both apartments and houses) including space and water heating, cooling, lighting and the use of appliances. In order to understand the evolution of household energy use, a set of indicators has been developed. For instance, several factors affect energy consumption for space heating as a share of households' energy demand. These factors include, dwelling size, number of occupants, the efficiency of heating equipment and the useful energy intensity. The paper also analyzes the trend of energy consumption in the residential sector of the United States. Moreover, the effects of important indicators on the energy consumption are discussed. The analysis performed in this paper is done for each census region, where possible, to elucidate the effects of different indicators in each region."
Value Criteria	Provide important new insights (new information for energy modeling)
Dataset	NA
Citation	Kialashaki, Arash, and John R. Reisel. "Modeling of the energy demand of the residential sector in the United States using regression models and artificial neural networks." Applied Energy 108 (August 2013): 271-280. https://doi.org/10.1016/j.apenergy.2013.03.034
Additional Information	This resource added by EPRI staff; not part of official methodology.

Article Title	Prospects for Energy Economy Modelling with Big Data: Hype, Eliminating Blind Spots, or Revolutionising the State of the Art? (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Review of use of big data for energy modeling
Subject Area	Energy modeling
Program Area	P201
Abstract	"Energy economy models are central to decision making on energy and climate issues in the 21st century, such as informing the design of deep decarbonisation strategies under the Paris Agreement. Designing policies that are aimed at achieving such radical transitions in the energy system will require ever more in-depth modelling of end-use demand, efficiency and fuel switching, as well as an increasing need for regional, sectoral, and agent disaggregation to capture technological, jurisdictional and policy detail. Building and using these models entails complex trade-offs between the level of detail, the size of the system boundary, and the available computing resources. The availability of data to characterise key energy system sectors and interactions is also a key driver of model structure and parameterisation, and there are many blind spots and design compromises that are caused by data scarcity. We may soon, however, live in a world of data abundance, potentially enabling previously impossible levels of resolution and coverage in energy economy models. But while big data concepts and platforms have already begun to be used in a number of selected energy research applications, their potential to improve or even completely revolutionise energy economy modelling has been almost completely overlooked in the existing literature. In this paper, we explore the challenges and possibilities of this emerging frontier. We identify critical gaps and opportunities for the field, as well as developing foundational concepts for guiding the future application of big data to energy economy modelling, with reference to the existing literature on decision making under uncertainty, scenario analysis and the philosophy of science."
Value Criteria	Provide important new insights (potential for improved model/simulation accuracy, new information for energy forecasting)
Dataset	NA
Citation	Li, Francis G. N., Chris Bataille, Steve Pye, and Aidan O'Sullivan. "Prospects for Energy Economy Modelling with Big Data: Hype, Eliminating Blind Spots, or Revolutionising the State of the Art?" Applied Energy 239 (April 1, 2019): 991–1002. https://doi.org/10.1016/j.apenergy.2019.02.002.
Additional Information	This paper provides a literature review on the use of big data for energy modeling. Notably, the review states that "…our 200+ paper review finds that the application of modern data science specifically to energy economy modelling and the implications for strategic decision making on energy and climate mitigation policy remain entirely unexplored." The study did find big data used in energy/technology policy in other domains.

References

Chang, Ruidong, and Yilong Han. "Is the U.S. Building Sector on a Low-Carbon Transition Trajectory? - Evidence from Building Performance Big Data." SSRN Scholarly Paper. Rochester, NY: Social Science Research Network, June 5, 2019. https://papers.ssrn.com/abstract=3399333.

Cohen, Stuart M., and Justin Caron. “The Economic Impacts of High Wind Penetration Scenarios in the United States.” *Energy Economics* 76 (October 1, 2018): 558–73. https://doi.org/10.1016/j.eneco.2018.10.023.

Kialashaki, Arash, and John R. Reisel. “Modeling of the energy demand of te residential sector in the United States using regression models and artificial neural networks.” *Applied Energy* 108 (August 2013): 271-280. https://doi.org/10.1016/j.apenergy.2013.03.034.

Kialashaki, Arash, and John R. Reisel. “Development and Validation of Artificial Neural Network Models of the Energy Demand in the Industrial Sector of the United States.” *Energy* 76 (November 1, 2014): 749–60. https://doi.org/10.1016/j.energy.2014.08.072.

Li, Francis G. N., Chris Bataille, Steve Pye, and Aidan O’Sullivan. “Prospects for Energy Economy Modelling with Big Data: Hype, Eliminating Blind Spots, or Revolutionising the State of the Art?” *Applied Energy* 239 (April 1, 2019): 991–1002. https://doi.org/10.1016/j.apenergy.2019.02.002.

Victor, Nadejda, Christopher Nichols, and Charles Zelek. “The U.S. Power Sector Decarbonization: Investigating Technology Options with MARKAL Nine-Region Model.” *Energy Economics* 73 (June 1, 2018): 410–25. https://doi.org/10.1016/j.eneco.2018.03.021.

9
P203 – AIR QUALITY AND MULTIMEDIA CHARACTERIZATION, ASSESSMENT AND HEALTH

Overall Commentary on the Literature Review Findings

The search string terms for P203 (detailed in the table below) identified predominantly papers utilizing satellite data for estimation of air quality parameters. The remainder of the studies were focused on air quality from sensors, planes, or a few novel methods.

With regard to **satellite-based air quality studies**, Hoff and Christopher (2009) provided an extremely comprehensive literature review and analysis, starting from a broad review of remote sensing technology relevant to air pollution, to listing all relevant satellites and species measured (a helpful reference), and finally focusing on air quality estimation (including through application of neural networks) and monitoring from satellite data. The authors noted the constituents which could be measured from satellite data: "Trace gases such as ozone, nitric oxide, nitrogen dioxide, water, oxygen/tetraoxygen, bromine oxide, sulfur dioxide, formaldehyde, glyoxal, chlorine dioxide, chlorine monoxide, and nitrate radical have been measured in the stratosphere and troposphere in column measurements." A broad conclusion from the paper was that satellite data worked well in "applications such as event identification (especially fires), transport, and atmospheric composition determination." The authors also note that satellite data would not be appropriate for compliance purposes:

> "…the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring (aerosol optical depth) AOD is +/-20%, and the relationship to PM2.5 is at best +/-30% in controlled measurements in which overlying aerosols, aerosol type, and boundary layer structure are known. This is not currently sufficient for regulatory use."

Several studies utilized both ground-based and satellite data for **air quality specific to power plant emissions**. While it is difficult to judge from the abstracts of these papers whether the data used is "big data" or whether the techniques fall firmly within the realm of data science, we present them as interesting applications of satellite data to electric power sector air quality issues. Shen et al. (2004) used a time series (26 days) of Atmospheric Infrared Sounder (AIRS) satellite data to analyze SO2 emissions at two coal power plants in northern New Mexico. De Foy et al. (2015) used the Ozone Monitoring Instrument (OMI) satellite data and also ground-based continuous emissions data (from the Continuous Emission Monitoring System, or CEMS) from 29 power plants in the U.S. to improve models for NOx.

A 2016 Nature article (Lewis and Edwards) laid out the trends and issues with an emerging technology - new **low cost air quality sensors** - and generally argued for assessment of the quality of the sensors. A number of studies and conference papers from the late 2010s were identified that used some form of low cost air quality sensors at the city level (e.g., sensors on buses in Zurich – Hasenfrantz et al., 2015; sensors on citizens' cars in Sydney – Sivaraman et al., 2013). Yi et al. (2015) conducted a helpful 'census' of these air quality sensor studies and categorized the studies by types of sensor networks: Static Sensor Network (SSN), Community

Sensor Network (CSN) and Vehicle Sensor Network (VSN). An exemplar of these studies is Apte et al. (2017), who used Google Street View car-mounted air quality sensors to develop a map of local air quality (NO, NO2 and black carbon) with "surprisingly sharp small-scale variability." Hasenfratz et al. (2012) also interestingly incorporated calibration of mobile air quality sensors: "We improve measurement accuracy by… exploiting sensor readings near governmental measurement stations to keep sensor calibration up to date."

Additional technology identified in the literature included:

- A plane-mounted 'spectrometer system' measuring CO2, CH4, and O2 was flown over power plants in Germany with estimates +/-10% of emissions reported by the power plants (Krings et al., 2011). The resolution of the data was 29m x 33m, which the authors noted filled a gap between local monitors and coarse satellite-based monitoring. A similar but stationary "imaging differential optical adsorption spectroscopy" (I-DOAS) was used to estimate SO2 from a Korean power plant (Chong et al., 2016);
- "Use of distributed artificial intelligence approaches" for monitoring power plant emissions in Romania (Dragomir and Oprea, 2013);
- Microscopy and machine-learning to quantify particulate matter (Wu et al. 2017); and
- Predicting NOx in flue gas using 'flame radical imaging' and ANN (Li et al., 2012).

On a **broader theme**, Liu et al. (2007) called for more integrated, interoperable air quality data, "a set of intelligent, robust algorithms and models for environmental modelling," and user interfaces to tap into the data and applications.

Table 9-1
Search strings for program 203

Data Science Terms	+ Program Area Terms	Google Scholar Results	# of Search Results Scanned	# Articles Reviewed Further
("neural network" OR "artificial intelligence" OR "remote sensing" OR "machine learning" OR "big data" OR "sensor")	("air quality" OR "air pollutant" OR "air pollution")	18,100	100	23
	("air pollutant fate" OR "air pollutant transport" OR "TRI reporting" OR "air pollution characterization")	417	100	1
	("decarbonization" OR "economic impacts of decarbonization" OR "decarbonization cost")	2,170	100	1
	("power plant emissions" OR "power plant discharge" or "NOx deposition" OR "SOx deposition")	4	4	1
	("power plant emissions")	1,290	200	17
Total				**43**
Articles highlighted				**7**

Highlighted Literature

Article Title	A Survey of Wireless Sensor Network Based Air Pollution Monitoring Systems (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of wireless sensor networks for air quality monitoring
Subject Area	Urban air quality
Program Area	P203
Abstract	"The air quality in urban areas is a major concern in modern cities due to significant impacts of air pollution on public health, global environment, and worldwide economy. Recent studies reveal the importance of micro-level pollution information, including human personal exposure and acute exposure to air pollutants. A real-time system with high spatio-temporal resolution is essential because of the limited data availability and non-scalability of conventional air pollution monitoring systems. Currently, researchers focus on the concept of The Next Generation Air Pollution Monitoring System (TNGAPMS) and have achieved significant breakthroughs by utilizing the advance sensing technologies, MicroElectroMechanical Systems (MEMS) and Wireless Sensor Network (WSN). However, there exist potential problems of these newly proposed systems, namely the lack of 3D data acquisition ability and the flexibility of the sensor network. In this paper, we classify the existing works into three categories as Static Sensor Network (SSN), Community Sensor Network (CSN) and Vehicle Sensor Network (VSN) based on the carriers of the sensors. Comprehensive reviews and comparisons among these three types of sensor networks were also performed. Last but not least, we discuss the limitations of the existing works and conclude the objectives that we want to achieve in future systems."
Value Criteria	Improve environmental, health, or safety outcomes (improved public health outcomes from data-informed resource management) Provide important new insights (near real-time, improved spatial and temporal resolution of information for decision making)
Dataset	NA
Citation	Yi, Wei Ying, Kin Ming Lo, Terrence S. T. Mak, Kwong-Sak Leung, Yee Leung, and Helen M. Meng. "A Survey of Wireless Sensor Network Based Air Pollution Monitoring Systems." In Sensors, 2015. https://doi.org/10.3390/s151229859.
Additional Information	Conducted a helpful 'census' of low cost air quality sensor studies and categorized the studies by types of sensor networks: Static Sensor Network (SSN), Community Sensor Network (CSN) and Vehicle Sensor Network (VSN).

Article Title	Estimates of Power Plant NOx Emissions and Lifetimes from OMI NO2 Satellite Retrievals (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of satellite data to estimate power plant emissions
Subject Area	Air quality from power plants
Program Area	P203

Abstract	"Isolated power plants with well characterized emissions serve as an ideal test case of methods to estimate emissions using satellite data. In this study we evaluate the Exponentially-Modified Gaussian (EMG) method and the box model method based on mass balance for estimating known NOx emissions from satellite retrievals made by the Ozone Monitoring Instrument (OMI). We consider 29 power plants in the USA which have large NOx plumes that do not overlap with other sources and which have emissions data from the Continuous Emission Monitoring System (CEMS). This enables us to identify constraints required by the methods, such as which wind data to use and how to calculate background values. We found that the lifetimes estimated by the methods are too short to be representative of the chemical lifetime. Instead, we introduce a separate lifetime parameter to account for the discrepancy between estimates using real data and those that theory would predict. In terms of emissions, the EMG method required averages from multiple years to give accurate results, whereas the box model method gave accurate results for individual ozone seasons."
Value Criteria	Provide important new insights (potential for improved model accuracy)
Dataset	NA
Citation	De Foy, Benjamin, Zifeng Lu, David G. Streets, Lok N. Lamsal, and Bryan N. Duncan. "Estimates of Power Plant NOx Emissions and Lifetimes from OMI NO2 Satellite Retrievals." Atmospheric Environment 116 (September 1, 2015): 1–11. https://doi.org/10.1016/j.atmosenv.2015.05.056.
Additional Information	De Foy et al. (2015) used the Ozone Monitoring Instrument (OMI) satellite data and also ground-based continuous emissions data (from the Continuous Emission Monitoring System, or CEMS) from 29 power plants in the U.S. to improve models for NOx.

Article Title	High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of low cost sensors for urban air quality monitoring
Subject Area	Urban air quality
Program Area	P203
Abstract	"Air pollution affects billions of people worldwide, yet ambient pollution measurements are limited for much of the world. Urban air pollution concentrations vary sharply over short distances (<1 km) owing to unevenly distributed emission sources, dilution, and physicochemical transformations. Accordingly, even where present, conventional fixed-site pollution monitoring methods lack the spatial resolution needed to characterize heterogeneous human exposures and localized pollution hotspots. Here, we demonstrate a measurement approach to reveal urban air pollution patterns at 4–5 orders of magnitude greater spatial precision than possible with current central-site ambient monitoring. We equipped Google Street View vehicles with a fast-response pollution measurement platform and repeatedly sampled every street in a 30-km2 area of Oakland, CA, developing the largest urban air quality data set of its type. Resulting maps of annual daytime NO, NO2, and black carbon at 30 m-scale reveal stable, persistent pollution patterns with surprisingly sharp small-scale variability attributable to local sources, up to 5–8x within individual city blocks. Since local variation in air quality profoundly impacts public health and environmental equity, our results have important implications for how air pollution is measured and managed. If validated elsewhere, this readily scalable measurement approach could address major air quality data gaps worldwide."

Value Criteria	Reduce costs (of monitoring) Improve environmental, health, or safety outcomes (improved public health outcomes from data-informed resource management) Provide important new insights (improved spatial and temporal resolution of information for decision making)
Dataset	NA
Citation	Apte, Joshua S., Kyle P. Messier, Shahzad Gani, Michael Brauer, Thomas W. Kirchstetter, Melissa M. Lunden, Julian D. Marshall, Christopher J. Portier, Roel C.H. Vermeulen, and Steven P. Hamburg. "High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data." Environmental Science & Technology 51, no. 12 (June 20, 2017): 6999–7008. https://doi.org/10.1021/acs.est.7b00891.
Additional Information	A number of studies and conference papers from the late 2010's were identified that used some form of low cost air quality sensors at the city level. An exemplar of these studies is Apte et al. (2017), who used Google Street View car-mounted air quality sensors to develop a map of local air quality (NO, NO2 and black carbon) with "surprisingly sharp small-scale variability."

Article Title	MAMAP – a New Spectrometer System for Column-Averaged Methane and Carbon Dioxide Observations from Aircraft: Retrieval Algorithm and First Inversions for Point Source Emission Rates (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of plane-mounted spectrometer to measure emissions over power plants
Subject Area	Air quality monitoring
Program Area	P203
Abstract	"MAMAP is an airborne passive remote sensing instrument designed to measure the dry columns of methane and carbon dioxide. The MAMAP instrument comprises two optical grating spectrometers: the first observing in the short wave infrared band (SWIR) at 1590–1690 nm to measure CO and CH absorptions, and the second in the near infrared (NIR) at 757–768 nm to measure O absorptions for reference/normalization purposes. MAMAP can be operated in both nadir and zenith geometry during the flight. Mounted on an airplane, MAMAP surveys areas on regional to local scales with a ground pixel resolution of approximately 29 m × 33 m for a typical aircraft altitude of 1250 m and a velocity of 200 km. The retrieval precision of the measured column relative to background is typically <1% (1σ). MAMAP measurements are valuable to close the gap between satellite data, having global coverage but with a rather coarse resolution, on the one hand, and highly accurate in situ measurements with sparse coverage on the other hand. In July 2007, test flights were performed over two coal-fired power plants operated by Vattenfall Europe Generation AG: Jänschwalde (27.4 Mt CO) and Schwarze Pumpe (11.9 Mt CO), about 100 km southeast of Berlin, Germany. By using two different inversion approaches, one based on an optimal estimation scheme to fit Gaussian plume models from multiple sources to the data, and another using a simple Gaussian integral method, the emission rates can be determined and compared with emissions reported by Vattenfall Europe. An extensive error analysis for the retrieval's dry column results (CO and CH) and for the two inversion methods has been performed. Both methods – the Gaussian plume model fit and the Gaussian integral method – are capable of deriving estimates for strong point source emission rates that are within

	±10% of the reported values, given appropriate flight patterns and detailed knowledge of wind conditions."
Value Criteria	Provide important new insights (improved spatial and temporal resolution of information for decision making)
Dataset	NA
Citation	Krings, T., K. Gerilowski, M. Buchwitz, M. Reuter, A. Tretner, J. Erzinger, D. Heinze, U. Pflüger, J. P. Burrows, and H. Bovensmann. "MAMAP – a New Spectrometer System for Column-Averaged Methane and Carbon Dioxide Observations from Aircraft: Retrieval Algorithm and First Inversions for Point Source Emission Rates." Atmospheric Measurement Techniques 4, no. 9 (September 6, 2011): 1735–58. https://doi.org/10.5194/amt-4-1735-2011.
Additional Information	A plane-mounted 'spectrometer system' measuring CO2, CH4, and O2 was flown over power plants in Germany with estimates +/-10% of emissions reported by the power plants (Krings et al., 2011). The resolution of the data was 29m x 33m, which the authors noted filled a gap between local monitors and coarse satellite-based monitoring.

Article Title	Prediction of NOx Emissions Throughflame Radical Imaging and Neural Network Based Soft Computing (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of flame radical imaging and ANN to estimate emissions in flue gas
Subject Area	Air pollution component analysis
Program Area	P203
Abstract	"The characteristics of reacting radicals in a flame are crucial for an in-depth understanding of the formation process of combustion emissions. This paper presents an algorithm for the prediction of NOx (NO and NO2) emissions in flue gas through flame radical imaging, flame temperature monitoring and application of Neural Network techniques. Radiation images of flame radicals OH*, CN*, CH* and C2* are captured using an intensified multi-wavelength imaging system. Flame temperature is determined using a spectrometer and two-color pyrometry. Based on these images, the characteristic values of the flame radicals are extracted. These characteristic values, together with the flame temperature, are then used to predict NOx emissions. Experimental results from a laboratory-scale gas-fired combustion rig have shown the effectiveness of the proposed method for the prediction of NOx emissions."
Value Criteria	Reduce regulatory risk (predict emissions) Provide important new insights (potential improved model accuracy)
Dataset	NA
Citation	Li, X., D. Sun, G. Lu, J. Krabicka, and Y. Yan. "Prediction of NOx Emissions Throughflame Radical Imaging and Neural Network Based Soft Computing." In 2012 IEEE International Conference on Imaging Systems and Techniques Proceedings, 502–5, 2012. https://doi.org/10.1109/IST.2012.6295594.
Additional Information	The paper presents technology that predicts NOx in flue gas using 'flame radical imaging' and ANN.

Article Title	Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land? (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of satellite data to estimate air quality
Subject Area	Air quality monitoring
Program Area	P203
Abstract	"The recent literature on satellite remote sensing of air quality is reviewed. 2009 is the 50th anniversary of the first satellite atmospheric observations. For the first 40 of those years, atmospheric composition measurements, meteorology, and atmospheric structure and dynamics dominated the missions launched. Since 1995, 42 instruments relevant to air quality measurements have been put into orbit. Trace gases such as ozone, nitric oxide, nitrogen dioxide, water, oxygen/tetraoxygen, bromine oxide, sulfur dioxide, formaldehyde, glyoxal, chlorine dioxide, chlorine monoxide, and nitrate radical have been measured in the stratosphere and troposphere in column measurements. Aerosol optical depth (AOD) is a focus of this review and a significant body of literature exists that shows that ground-level fine particulate matter (PM2.5) can be estimated from columnar AOD. Precision of the measurement of AOD is ±20% and the prediction of PM2.5 from AOD is order ±30% in the most careful studies. The air quality needs that can use such predictions are examined. Satellite measurements are important to event detection, transport and model prediction, and emission estimation. It is suggested that ground-based measurements, models, and satellite measurements should be viewed as a system, each component of which is necessary to better understand air quality."
Value Criteria	Reduce costs (potential reduced monitoring costs) Improve environmental, health, or safety outcomes (improved public health outcomes from data-informed resource management)
Dataset	NA
Citation	Hoff, Raymond M., and Sundar A. Christopher. "Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land?" Journal of the Air & Waste Management Association 59, no. 6 (June 1, 2009): 645–75. https://doi.org/10.3155/1047-3289.59.6.645.
Additional Information	Extremely comprehensive literature review and analysis of satellite based air quality monitoring, starting from a broad review of remote sensing technology relevant to air pollution, then listing all relevant satellites and species measured (a helpful reference), and finally focusing on air quality monitoring from satellite data.

Article Title	Validate Personal Air-Pollution Sensors (Stage: completed, Source type: literature)
Emerging Technology or Data Science Element	Use of low cost sensors for urban air quality monitoring
Subject Area	Urban air quality
Program Area	P203
Abstract	"Alastair Lewis and Peter Edwards call on researchers to test the accuracy of low-cost monitoring devices before regulators are flooded with questionable air-quality data."
Value Criteria	Reduce costs (low-cost monitoring)
Dataset	NA
Citation	Lewis, Alastair, and Peter Edwards. "Validate Personal Air-Pollution Sensors." Nature News 535, no. 7610 (July 7, 2016): 29. https://doi.org/10.1038/535029a.
Additional Information	*Nature* article that lays out the trends and issues with new low cost air quality sensors and generally argued for assessment of the quality of the sensors.

References

Apte, Joshua S., Kyle P. Messier, Shahzad Gani, Michael Brauer, Thomas W. Kirchstetter, Melissa M. Lunden, Julian D. Marshall, Christopher J. Portier, Roel C.H. Vermeulen, and Steven P. Hamburg. "High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data." *Environmental Science & Technology* 51, no. 12 (June 20, 2017): 6999–7008. https://doi.org/10.1021/acs.est.7b00891.

Chong, Jihyo, Young J. Kim, Jongho Baek, and Hanlim Lee. "Estimation of Sulphur Dioxide Emission Rate from a Power Plant Based on the Remote Sensing Measurement with an Imaging-DOAS Instrument." In *Remote Sensing of Clouds and the Atmosphere XXI*, 10001:1000112. International Society for Optics and Photonics, 2016. https://doi.org/10.1117/12.2241775.

Dragomir, Elia Georgiana, and Mihaela Oprea. "A Multi-Agent System for Power Plants Air Pollution Monitoring." *IFAC Proceedings Volumes*, 2nd IFAC Workshop on Convergence of Information Technologies and Control Methods with Power Systems, 46, no. 6 (January 1, 2013): 89–94. https://doi.org/10.3182/20130522-3-RO-4035.00017.

Foy, Benjamin de, Zifeng Lu, David G. Streets, Lok N. Lamsal, and Bryan N. Duncan. "Estimates of Power Plant NOx Emissions and Lifetimes from OMI NO2 Satellite Retrievals." *Atmospheric Environment* 116 (September 1, 2015): 1–11. https://doi.org/10.1016/j.atmosenv.2015.05.056.

Hasenfratz, David, Olga Saukh, Silvan Sturzenegger, and Lothar Thiele. "Participatory Air Pollution Monitoring Using Smartphones," 2012.

Hasenfratz, David, Olga Saukh, Christoph Walser, Christoph Hueglin, Martin Fierz, Tabita Arn, Jan Beutel, and Lothar Thiele. "Deriving High-Resolution Urban Air Pollution Maps Using Mobile Sensor Nodes." *Pervasive and Mobile Computing*, Selected Papers from the Twelfth Annual IEEE International Conference on Pervasive Computing and Communications (PerCom 2014), 16 (January 1, 2015): 268–85. https://doi.org/10.1016/j.pmcj.2014.11.008.

Hoff, Raymond M., and Sundar A. Christopher. “Remote Sensing of Particulate Pollution from Space: Have We Reached the Promised Land?” *Journal of the Air & Waste Management Association* 59, no. 6 (June 1, 2009): 645–75. https://doi.org/10.3155/1047-3289.59.6.645.

Krings, T., K. Gerilowski, M. Buchwitz, M. Reuter, A. Tretner, J. Erzinger, D. Heinze, U. Pflüger, J. P. Burrows, and H. Bovensmann. “MAMAP – a New Spectrometer System for Column-Averaged Methane and Carbon Dioxide Observations from Aircraft: Retrieval Algorithm and First Inversions for Point Source Emission Rates.” *Atmospheric Measurement Techniques* 4, no. 9 (September 6, 2011): 1735–58. https://doi.org/10.5194/amt-4-1735-2011.

Lewis, Alastair, and Peter Edwards. “Validate Personal Air-Pollution Sensors.” *Nature News* 535, no. 7610 (July 7, 2016): 29. https://doi.org/10.1038/535029a.

Li, X., D. Sun, G. Lu, J. Krabicka, and Y. Yan. “Prediction of NOx Emissions Throughflame Radical Imaging and Neural Network Based Soft Computing.” In *2012 IEEE International Conference on Imaging Systems and Techniques Proceedings*, 502–5, 2012. https://doi.org/10.1109/IST.2012.6295594.

Liu, Gang-jun, Er-jiang Fu, Yun-jia Wang, Ke-fei Zhang, Bao-ping Han, and Colin Arrowsmith. “A Framework of Environmental Modelling and Information Sharing for Urban Air Pollution Control and Management.” *Journal of China University of Mining and Technology* 17, no. 2 (June 1, 2007): 172–78. https://doi.org/10.1016/S1006-1266(07)60066-2.

Marć, Mariusz, Marek Tobiszewski, Bożena Zabiegała, Miguel de la Guardia, and Jacek Namieśnik. “Current Air Quality Analytics and Monitoring: A Review.” *Analytica Chimica Acta* 853 (January 1, 2015): 116–26. https://doi.org/10.1016/j.aca.2014.10.018.

Shen, Sylvia S., David P. Miller, and Paul E. Lewis. “Analysis of SO2 Point Source Emissions Using NASA Atmospheric Infrared Sounder Data.” In *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII*, 6565:65651L. International Society for Optics and Photonics, 2007. https://doi.org/10.1117/12.720837.

Sivaraman, V., J. Carrapetta, K. Hu, and B. G. Luxan. “HazeWatch: A Participatory Sensor System for Monitoring Air Pollution in Sydney.” In *38th Annual IEEE Conference on Local Computer Networks - Workshops*, 56–64, 2013. https://doi.org/10.1109/LCNW.2013.6758498.

Spinelle, Laurent, Michel Gerboles, Maria Gabriella Villani, Manuel Aleixandre, and Fausto Bonavitacola. “Field Calibration of a Cluster of Low-Cost Available Sensors for Air Quality Monitoring. Part A: Ozone and Nitrogen Dioxide.” *Sensors and Actuators B: Chemical* 215 (August 1, 2015): 249–57. https://doi.org/10.1016/j.snb.2015.03.031.

Wu, Yi-Chen, Ashutosh Shiledar, Yi-Cheng Li, Jeffrey Wong, Steve Feng, Xuan Chen, Christine Chen, et al. “Air Quality Monitoring Using Mobile Microscopy and Machine Learning.” *Light: Science & Applications* 6, no. 9 (September 2017): e17046. https://doi.org/10.1038/lsa.2017.46.

Yi, Wei Ying, Kin Ming Lo, Terrence S. T. Mak, Kwong-Sak Leung, Yee Leung, and Helen M. Meng. “A Survey of Wireless Sensor Network Based Air Pollution Monitoring Systems.” In *Sensors*, 2015. https://doi.org/10.3390/s151229859.

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