**Project Title:** Using computer vision to identify onsite wastewater systems

**Background**

The field of Environmental Science has a long-standing history of using remote monitoring approaches to assess a wide variety of conditions that include weather, geologic, and man-made features. (lit review needed) Computational capacity has increased significantly in recent years, allowing the development of a number of novel approaches to analyzing and interpreting digital images, a process some now labeled as “computer vision.” Machine learning approaches, particularly neural networks, can use the relationships between groups of values to develop models that identify features. The most common current approaches in the area of computer vision use supervised learning. This approach “trains” a neural network by processing (often many times) a set of images with features that have been labeled by human subject matter experts until it is able to identify these features with some degree of accuracy. A separate set of images that have also been labeled, but the model has not yet analyzed, is then evaluated by the model to assess the accuracy of the model in identifying these features. Iterative approaches to train and test the model can be used to improve the accuracy and evaluate its performance across a variety of images.

While computer vision-related work has a long history of use in environmental science (often labeled as “remote sensing”) there has been very little use of computer vision in environmental public health to-date. Staff at the Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) have piloted the use of computer vision approaches to identify water cooling towers in metropolitan areas. This project was intended to be used by public health staff during investigations of legionnaires disease or Pontiac Fever so they could more readily identify water cooling towers, a common source of the *Legionella* bacteria that cause these diseases. ([reference CDC](https://www.cdc.gov/legionella/index.html)) The project achieved a 90% accuracy and continues to be evaluated and improved.

Traditional statistical approaches using multi-variable models to predict the presence or absence of a system from a set of variables as well as the system’s potential functionality (i.e., failed versus functioning) may also assist jurisdictions with this work. Examples of these approaches include xxx, xxx, xxx.

Researchers from the CDC, ATSDR, and the Environmental Protection Agency (EPA) engaged federal, state, and local environmental protection and health agencies to assess the past or present use of traditional statistical and computer vision approaches to identify onsite wastewater systems. The outreach included an assessment of any realized or potential benefit to improve environmental public health practice. These discussions led to the decision that there was utility to both the field and environmental public health practice in exploring this topic in more depth. The group of experts determined that piloting this work with multi-family onsite wastewater systems (aka “package systems”) would provide the greatest chance of success and a further proof of concept for this approach.

The intent of this project is to explore the utility in applying traditional multivariable models and supervised machine learning approaches to identify off-site decentralized wastewater treatment systems (aka community wastewater package treatment plants). The primary focus will start with accurate identification of a septic system with a secondary evaluation of whether it would be possible to distinguish currently-functioning systems from failed ones. Initial efforts will start with identification of multi-family wastewater systems (aka “package systems”) with potential later work on individual household systems. If successful, this approach will greatly relieve the resource requirements for CDC and jurisdictional programs to accurately identify onsite wastewater systems. This work will also advance this field’s use of this potentially powerful approach for use in other public health issues.

### Package waste water treatment systems

Community wastewater treatment systems, are off-site systems for decentralized disposal of domestic sewage. Cluster sewage systems collect wastewater from two or more dwellings or buildings and convey it to a treatment and dispersal system located on a suitable site near the dwellings or buildings. These systems, also known as package wastewater treatment plants (“package plants”), are recommended for use in areas where soil conditions are unsuitable for subsurface sewage drainage fields and/or where centralized municipal sewerage systems are not available or cost effective (Gaydon , 2007).

The Clean Water Act of 1972 included a grant program that financed the construction of community wastewater treatment plants throughout the United States. The 1987 Water Quality Act replaced the construction grant program with the Clean Water State Revolving Fund that encourage water quality improvement project through EPA-state partnerships (EPA 2024a; 2024b; LADH 2024). The current Louisiana Clean Water State Revolving Fund was instituted in 1997, well after implementation of the 1982 Water Quality Act. In the interim there was a lapse of federal funding for centralized sewage systems in the state (LADH, 2024). Coinciding with the 1990s laps in federal funding for construction of centralized sewage treatment facilities was an unforeseen boom in suburban growth along newly constructed interstate corridors. These interstate corridors are characteristically marshy clay-like soil with a high water table that precludes soil percolation and is therefore unsuitable for typical on-site treating of residential sewage utilizing a septic tank and drainfield. In Louisiana, a common alternative for residential sewage treatment has been on-site aerated treatment units (ATUs). However, ATUs are intended for isolated homes in rural areas of widely-separated dwellings and release partially treated sewage that relies on additional “downstream” treatment (i.e.,drainfields, sand filter, disinfection) for final treatment. Even when properly maintained and operated, ATUs historically exceed the Total Suspended Solids (TSS) and Biochemical Oxygen Demand at day five (BOD5) limits (NESC, 2005).

Community package treatment use many different technologies and configurations which are largely dictated by both cost and site-related factors. Cost considerations include the costs of equipment, maintenance and the land where the plan will be located. Site related factors include average daily flow, housing density, terrain (slope, soil, water table), available space and local regulatory requirements. Consequently, the various designs used for a package plants results in systems with different “looks” (Ohio EPA, 2015). In general, the treatment process for domestic wastewater consists of four steps: pre-treatment, primary treatment, secondary treatment, and tertiary treatment. The first two stages of treatment are common in all treatment technologies but are frequently combined in a package plant. Pretreatment removes coarse materials that can be easily collected from the raw sewage including non-biodegradable or inert contaminants: sand, gravel and plastic or paper trash. Pretreatment can include screening, grinding and skimming, as well as flow equalization if the plant requires flow be regulated. Secondary sewage treatment removes as much of the solid material as possible and often relies on biological processes to digest and remove remaining soluble organic material and can range from entirely passive (constructed wetlands) to mechanical. In the U.S., activated sludge systems are the most common approaches of secondary treatment in package plants, which includes extended aeration, sequencing batch reactors (SBRs) and oxidation ditches (U.S. EPA, 2000). Alternative secondary treatment process rotating biological contactors (RBC), moving bed biofilm reactors(MBBR), sequencing batch biofilm reactors (SBBR), membrane Bioreactors (MBR), wet composting and others technologies (Gaydon, 2007, Ohio EPA, 2017, U.S. EPA, 2000). In activated sludge systems, bacteria-rich water flows from the aeration chamber to the clarifier where bacteria settle. The tertiary stage is the final step before discharge. Here, waste is filtered through sand, which removes fine suspended solids. In some states, including Ohio, Maryland and Virginia, plants with surface discharge must include final disinfection with chlorination followed by dechlorination or UV light of the effluent is required (Commonwealth of Virginia , 1990). Separate from the wastewater disinfection process is the solid handling stage. Balanced bacterial growth and removal is essential for efficient water treatment. When the bacterial load becomes excessive, bacteria are transferred from the secondary stage to the digester or sludge holding tank. It is the operator’s responsibility to recognize when the bacterial load exceeds limits and remove sufficient bacteria from the secondary stage. Eventually, the sludge in the digester tank must be pumped out to make space for more bacteria (Ohio EPA, 2015).

There are a number of concerns with the reliance on package treatment plants by a growing number of single family home and communities. First, for a package treatment plant to be functional, it must be properly installed. However, package plants are not always properly installed, which can include improperly setup and missing components (i.e., missing chlorination units, improper location of treatment plants or discharge points, or poorly designed sand filters that allow effluent to leak). Second, package plants are frequently not not properly operated and maintained, including absence of chlorine tablets, improper sludge removal, erroneously set valves, improperly operating pumps etc. A report by the State Water Control Board of Virginia concluded that many of these issues are often a result of the homeowners’ lack of interest understanding of proper plant operation or a failure to monitor effluent from these plants. Cost, responsibility and regulatory oversite are also issues. In Virginia, as in Louisiana, package plants are built by developers and may be deeded over to the homeowners when the development is completed. The homeowners generally do not have the knowledge, skills or resources to administer the proper operation and maintenance of these plants. Therefore, local governments often need to take over at considerable cost, and as a result some localities prohibit privately owned treatment plants for residential development (Commonwealth of Virginia , 1990).

### Decentralize septic in St Tammany Paris, LA

In Louisiana, many parishes and incorporated communities provide community drinking water but have little or no infrastructure for provision of community sewerage. St Tammany Parish (STP) is one of the fastest growing parishes in LA with a population that grew by 16.5% between 2010 and 2022, from 234,564 to 273,263. During the same period, the number of household increase by 25.5%, from 84536 to 106109 total households (USA FACTS, accessed 2024; Cooper, 2022). Although this rapid growth has had significant economic benefits, STP retains remnants of its rural past in its current development patterns, including widespread reliance on Aerated Treatment Units (ATUs) OWTS and community package waste treatment plants (STP Government, 2023; de Toledo Sobrinho, 2018). This population growth, along with the proliferation of homes in rural areas has outpaced centralized infrastructure development, which has been historically underfunded, and has led to a rapid increase in decentralized septic systems (Cooper, 2022). Per the LA Department of Health (LDH), there are as many as ~ 1200 subdivisions and phases in STP of which approximately 285 are unsewered neighborhoods (STP Government, 2023). It is estimated that between ~ 35,000 (STP estimate) to ~65000 (LDH estimate) STP households are unsewered (Cooper, 2022). The Parish hosts an unusually high number of privately owned and managed wastewater treatment plants, while lacking its own centralized Parish treatment plant(s). Although most homes in unincorporated parts of the Parish use on-site water treatment systems (OWTS), many unincorporated rural and suburban communities rely on community package wastewater treatment plants as an alternative to ATUs (Cooper 2022). This lack of a centralized and coordinated water management at the parish level fragments systems management of potential environmental contaminants that threaten surface water, ground water, and even drinking water, and contributes to growth of mosquitos and other pests.

Unlike conventional septic tank/drainfield systems and ATUs, Louisiana permits surface effluent discharge (including into surface water) from package plants that meet “the *minimum requirements* of the secondary treatment standard”. This standard is defined as the arithmetic mean of the 30-day biochemical oxygen demand of 30 mg/L (Louisiana Administrative Code Title 51). Unlike conventional septic systems, a well-designed, maintained and functioning package plant can produce a higher quality water discharge. Despite this advantage, most states require discharges into drainfields, thus removing one of the major benefit of package plants as an alternative to conventional on-site septic where drainfields are not feasible (Commonwealth of Virginia, 1990).

Beginning in 2016, STP Mosquito Abatement District (STPMAD) began surveillance of package treatment facilities for the production of southern house mosquitoes. Though most package plants kept water circulating inhibiting oviposition and development of mosquitoes, several became local sources of vector production.

### Computer Vision for Identifications of Failed Septic Systems

Remote imaging has been repeatedly used for identifying land surface sewage releases. Most frequently, these efforts have been targeted toward centralized sewage systems or decentralized individual septic failures. To our knowledge, there have been no efforts to use remote imaging to identify failed package plants.

Most published investigations begin with some geospatial knowledge of locations where septic systems are located. For example, failed decentralized on-site septic systems were identified as a source of bacterial contamination of subbasin water in the Huron River watershed region of Washtenaw County (WC), MI (Brenner and Vernier, 2012). Investigators used ancillary home data from property sales coupled with GIS analysis and county unsewered database to identify 4096 residential parcels using on-site septic systems. Further, aerial thermal and color infrared (CIR) imagery with a resolution of 0.6 m was obtained during the month of April in order to manually identify unusual moisture and biological activity of saturated drain fields. Image signatures were used to classify septic system failure. In collaboration with the WC Environmental Health Department (WCEHD), likely septic sites and drainfileds were identified from imagery and a random sample of on-site inspections were performed to verify predictions. Although the method effectively identified failed systems, the results were also characterized by a high false positive rate. Similar results have been previously reported for imaging-based detection of septic failure (Evans BM, 1982).

* Satellite methodologies for terrestrial septic system failure
  + Mason, Mapping Buildings across Heterogeneous Landscapes: Machine Learning and Deep Learning Applied to Multi-Modal Remote Sensing Data
  + Verhoeven-2006-Looking through Black-Tinted Glasses\_A Remotely Controlled Infrared Eye in the Sky
  + Orimoloye , 2020, Spatial evaluation of land‑use dynamics in gold mining area using remote sensing and GIS technology (See vegetation)
  + Alonso, Spatial and radiometric 1 characterization of multi-spectrum 2 satellite images through multifractal analysis
* ML algorithm for terrestrial septic system failure
  + Cardenas-Martinez , Predictive modelling benchmark of nitrate Vulnerable Zones at a regional scale based on Machine learning and remote sensing

**Methods**

This study underwent the CDC Human Subjects Review process and was considered exempt from review as it used publicly-available information without any personal identifiers.

Placeholders for methods topics

* Data was collected from (LA St. Tammany parish, others)
* Time period of data used
* Traditional statistical methods used
  + Variables
* CV approaches used (CNNs)
  + How many SMEs need to identify a system (maybe 2 independent with a 3rd person in a meeting to review and adjudicate any discrepancies?)Identifiable features of package plants
  + STP site information for package plants
  + Summary of types of failures as identified by STP HD or permitting agency
  + How to identify known failed systems to label.
  + Time periods needed
  + Vegetation indices to evaluate. Potential citation

Next steps, updated 5/9/24

* Focus on St. Tammany to start
  + Potential other partners:
    - NC DOH
    - RI DOH
    - GA Dept. of EH
    - [Massachusetts Alternative Septic System Test Center](https://www.masstc.org/)

**Anticipated results**

Table 1.

* Total # of known systems vs. # with sufficient data to evaluate
  + Sub columns for traditional statistical model and CNN models
* Univariable stats

Table 2. Bivariable

Table 3. Multivariable (traditional) stats results

Table 4. CNN results

* Sensitivity / specificity for any system
* Sensitivity / specificity for failed system

Figure 1. Example images from CNN work

* Example of an identified system
* Example of something that looks like a package system but is not

Discussion

This project evaluated the use of traditional and novel approaches to identifying

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