Odour Control Master Planning
using Innovative Integrated Approaches

Bart Kraakman[1], Scott Cowden[2], Bill Design[3], Jay Witherspoon[2]
[1] JACOBS/CH2M, Portland, OR, USA
[2] JACOBS/CH2M, Corvallis, OR, USA
[3] JACOBS/CH2M, Milwaukie, WI, USA
[4] JACOBS/CH2M, San Francisco, CA, USA

ABSTRACT

The cost for odour control for the collection and treatment of municipal and industrial wastewaters has increased over recent decades. The implementation costs for odour control at a water recovery facility (WRF), typically only a few percent of the facility's total build cost 20 years ago, is now sometimes close to 10% or more. The increase of these cost is driven by several relatively recent changes. Firstly, tighter controls of the waste, including metal waste which previously largely precipitated with odorous compounds. Secondly, water restrictions and innovations in water saving devices has resulted in an increase in the pollutant concentration in the sewer leading to increased septicity when entering the WRFs. Thirdly, there is a growing trend towards more centralized WRFs in many large cities, especially with the amalgamation of water authorities into larger utilities. In addition, there is often new community growth near the facilities. At the same time, many of these water utilities are seeing cost reduction demands driven by this same community to keep rates low.

Odour assessment tools, in the meanwhile, have been developed and/or dramatically improved over the last decade. Among them are mathematical models to predict the formation and dispersion of odours, odour characterization methodologies and odour field measurement equipment as well as odour control design and odour management decision roadmaps. All these tools are now available to be used for Odour Control Master Planning as well as to be used for communication means such as public outreach, community meetings and obtaining internal and external stakeholder support. They can foster better communication and understanding between both the facility, stakeholders and the community regarding conducting odour impact assessments and the impacts of proposed odour control measures to reduce existing odour levels experienced by the surrounding community.

This paper presents the Odour Control Master Planning Tool Set developed over the years by JACOBS/CH2M that has been used for planning and management purposes in selecting proper odour control criteria and prioritizing efforts tailored for the facility's individual funding abilities or to meet a site-specific community demand. In addition, multiple innovative integrated odour control approaches are presented that have been used to meet a set community-based odour criteria while minimizing the costs. The Tool Set can be used to balance O&M needs, funding, capital expenditures, and other needs to develop a comprehensive control program that is a "win" for both the community and the facility. The paper focusses on the water industry, but the Tool Set incorporates several activities and resources applicable to any other industry.

KEY WORDS
Odours, Odour Impact Assessment, Odour Control, Odour Control Master Planning, Odour Complaints, Public Outreach.

INTRODUCTION

Owners and operators of industrial facilities such as water recovery facilities (WRFs), including wastewater collection systems, are being faced with an increasing number of odour complaints and greater pressures to reduce offsite odour impacts. The main contributing factors for this are:

- Encroaching development of residential areas on existing WRFs and/or pump stations;
- Heavy metals largely being removed from the sewage due to tighter controls of the waste and consequently an increase in the formation of odorous compounds in the sewer;
- Expansions of the WRF and collection systems, which resulted in longer retention times in sewage networks;
- Water restrictions and innovations in water saving devices has resulted in an increase in the concentration of pollutants in the sewer leading to increased septicity;
- A more vocal and well-educated community concerned about loss of enjoyment in their homes and backyards and devaluation of their property;
- More stringent regulatory enforcement and regulations.

At the same time, tighter funding controls and greater accountability for spending and budgetary constraints, making justification of capital works and increased operational budgets more difficult.

To satisfy these competing drivers of greater community and regulatory expectations with financial issues, JACOBS/CH2M, with the help of several owners of large and small facilities, developed and employed Odour Control Master Planning Tools often using integrated approaches. An integrated approach looks at complex systems as a whole and sees if the individual components fulfill the main objective in a manner which result in integration of many different functions for collective optimum performance at minimum cost to the objective in a sustainable manner.

The Odour Control Master Planning Tool Set is successfully used over the years to evaluate the issues and obtain endorsement from all stakeholders for a mutually acceptable path forward. They can help the public to understand the need for reasonable reduction targets and, equally as important, the level of expenditure of time and money necessary to achieve their requirements. Combined with WRF operators’ experience, professional understanding of WRF operational issues, and understanding of cost effective treatment solutions, the Tool Set have shown to effectively manage odour problems for facility owners and operators. This systematic evaluation and prioritization of control solutions has helped focus attention to areas that achieve the best, immediate, short-term, and long-term solutions.

THE ODOUR CONTROL MASTER PLANNING APPROACH

The Odour Control Master Planning Tool Set incorporates a number of activities and resources that can be applied to any odour control project. **Figure 1** shows the main phase of the Tool Set, which include:

1. Chartering the Project. Team chartering is a structured process that establishes the goals, objectives, constraints, and critical success factors. The chartering process reviews project plans and verifies objectives, develops collaboration and decision-making, and results in agreement on approach. Involving all stakeholders in the decision-making process and agreeing on identifiable and quantifiable goals allows activities to occur with stakeholder support and more importantly their understanding.

   For example, sometimes specific odour management regulations are absent, other than general air quality requirements to prevent facilities from negatively affecting public health by the release of odorous gases. In the absence of specific regulatory-driven odour limits, the facility operator, local residents, and other stakeholders have to define the acceptable odour impact limits.

2. Assessing Current Situation. This step involves assessing the current situation and identifying and filling knowledge gaps. The information required includes odour emissions rates (and time), potential odour emissions from the collection system, and impact of influent wastewater on odour emissions from the WRF, and the actual and predicted extent of odour impact on areas surrounding the WRF. Specific tools used in this phase can include assessments, mathematical models, methodologies, or equivalent, to provide odour emission estimates. These tools are discussed in greater detail below.

3. Developing Odour Inventory. In addition, measuring odour emissions is another critical aspect and can be done using laboratory olfactometry (supported by field-based olfactometry), and chemical characterization of odorous compounds. Odour dispersion modeling is conducted to assess the estimated offsite odour impacts. This phase also includes a facility-wide risk assessment to potential odour releases under abnormal operating conditions (including fugitive odour emissions).

4. Developing Odour Control Alternatives. This step involves developing options to reduce offsite odour impacts. These alternatives can include a range of options that can be implemented both in the sewage collection network and the WRF, as well as plant integrated odour control techniques and “end-of-pipe” gas phase odour control equipment to meet the odour reduction goals agreed upon by all stakeholders.

5. Developing the Odour Control Master Plan. This step involves documenting the project and developing conclusions, recommendations, and an implementation plan for control and/or assessment measures. The odour control improvements are prioritized and incorporated into a capital improvement program (CIP) containing

immediate, short-term, and long-term solutions. It is a plan that can be communicated with quantifiable goals that allows activities to occur with stakeholder support and their complete understanding.

6. Implementing Public Outreach. This program ideally involves community stakeholders in all aspects of project planning and decision making. What level of involvement or influence is up to each facility owner and their needs associated with this effort. Many owners want their community to be educated to dispel negative perceptions and ungrounded fears. That level of community involvement can range from providing understanding of the Odour Control Master Plan efforts to having the community helping make the funding decisions on what should be implemented in the Odour Control Master Plan.

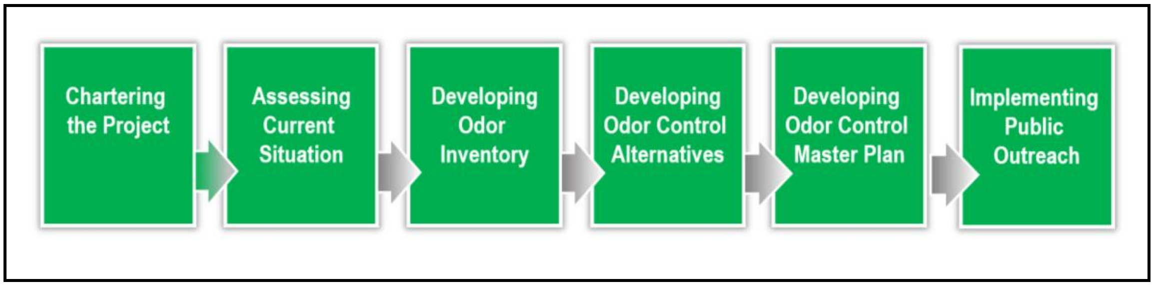

Figure 1: Odour Control Master Planning phases.

DISCUSSION AND EXAMPLES

The following sections present several examples that address how to successfully implement an Odour Control Master Plan.

Chartering the Project

Chartering develops collaboration and decision-making, and results in agreement on approach. Many jurisdictions have applicable regulations, policies, or guidelines aimed at protecting from nuisance odours and/or adverse odour impacts. Odour emissions, if not managed effectively, can manifest as complaints that result in poor public relations and regulatory consequences and fines.

Support of stakeholders is important and as well as their understanding of what factors contribute to odour nuisance. The factors that contribute to odours leading to an odour nuisance complaint are **F**requency, **I**ntensity, **D**uration, **O**ffensiveness and **L**ocation (FIDOL, see **Table 1**, which can be used to characterize the level and risk of odour nuisance [1].

Because of the specific local meteorological conditions at any site, it is not possible to control any of these factors once odours are released into the atmosphere. It is possible to control Frequency, Intensity, and Duration indirectly by releasing odours of such low concentration that once they are transported from the site they do not result in odour complaints. For this reason, regulators often focus on these three parameters (also called dose response criteria) when defining odour compliance limits based on predictive atmospheric dispersion modeling tools. While Frequency, Intensity and Duration can be easily measured, the Offensiveness as perceived by a person is more difficult to measure or predict. It is more difficult to influence the offense that a person takes to the presence of odours, because they are subjective and sometimes based on negative perceptions or perceived health risks.

Table 1: Odour nuisance characterizing parameters.

Odour Nuisance Parameter	**Explanation**
Frequency	How often an odour is experienced?
Intensity	How strong odour is above background odours? /what is the Odour Concentration (dilutions to threshold/Odour Units) or the Odour Intensity?
Duration	How long the odour is experienced at nuisance levels or is it always there?
Offensiveness	Hedonic Tone. How offensive the odour is to the person detecting it? (i.e. a wastewater treatment operator may respond differently than a school teacher)
Location or context	Where or under what context the odour is experienced and when? (e.g. at what time during the day or night or are there other factors such as loud noise that may affect the threshold level for nuisance).
others	Sometimes it is the knowledge of an activity generating the odour that causes an offensive reaction in people smelling the odour. In addition, people can get desensitized to background odours and become less aware of similar odours.

Through the employment of effective public outreach tools, it is possible to establish a relationship with the community and develop a forum to discuss their concerns, demystify the WRF operations, and build trust. Effective methods of establishing a positive relationship are:

- Training staff to communicate policies effectively
- Use established odour compliant procedures
- Newsletters and Webpages
- Open house tours and public meetings
- Smartphone apps to record and communicate the presence of odours
- Support citizen advisory functions
- Odour surveys and logs

These tools not only help to communicate facts to the public, but they also provide a forum for the community to offer reliable feedback that can be used to fine tune odour control projects and optimize operating procedures. When supplied with good information from sources they trust, the community is more likely to endorse and support mutually beneficial efforts. For example, it is possible to show that concentrations of odorous compounds are often so small that there is no potential for adverse health effects or that certain uncovered process units do not necessarily results in offensive odours. By building trust, communicating odour control strategies, and overcoming misconceptions, it is possible to get quality community feedback and endorsement and a reduction in odour complaints without relying solely on conventional odour control treatment methods (see also the section **Implementing Public Outreach**).

Odours emissions from most sources occur irregularly and are dependent on process and weather conditions making predicting odour impacts difficult. The time, effort and cost involved can be expensive determining odour impact levels using odour sampling. In addition, odour nuisance can result in complaints from the general public at odour concentrations below 10 Odour Units (OU) with most regulatory odour impact are set at levels of 1 OU to 10 OU. However, laboratory odour panels used to evaluate odour concentration cannot accurately determine the low odour concentrations at impact level. Dispersion modeling is a useful tool in predicting the concentration of dispersed odours from a WRF; however, dispersion modeling (normally computer-based dispersion modeling) has several limitations:

1. The model is only an approximation of "real life" atmospheric processes, and therefore all results are subject to interpretation and degrees of inaccuracy. Practitioners should back-up odour predictions with visits, field observations or field olfactometric measurements and inputs from people at the site or impact area.

2. The models are unable to account for the synergistic effects of multiple odour types and sources; and therefore, the model predictions must again be interpreted. In addition, odour intensities decrease with concentration at different rates for different odour constituents (also called odour persistency), which means that modelling the dispersion of only the odour concentration might not be sufficient.

3. The models are not able to predict how people will react to the odours or predict complaint levels – just probability of an odour complaint based on frequency of exposure or duration of exposure to the odours at potential nuisance odour levels.

The odour impact criteria generally take the form of a predicted odour concentration (e.g. 2 OU) that must not be exceeded for a specified percentage of the time (e.g. 99.5% of the time) based on a specified model averaging time (e.g. 15 minutes). The exceedance allowances are set to account for the frequency dose response component, to allow for the inexactness of the modeling, and to recognize that there might be some odour impact around facilities for short periods.

Given the nature of odour impacts, it is very difficult to measure the strength of odour impacts as they occur. However, for an odour control project to be successful there must be agreement between WRF operators, their surrounding communities, and regulators on how acceptable impact is to be defined. Dispersion modeling predictions are one such method and, as long as the aspects of modeling uncertainty are explained clearly to the communities involved, can be an effective tool for demonstrating potential and predicted actual odour impact reductions over time. Therefore, it is usually beneficial using dispersion models to calculate predicted odour concentrations and to collect odour impact data such as field olfactometric assessments and odour complaint data as verification.

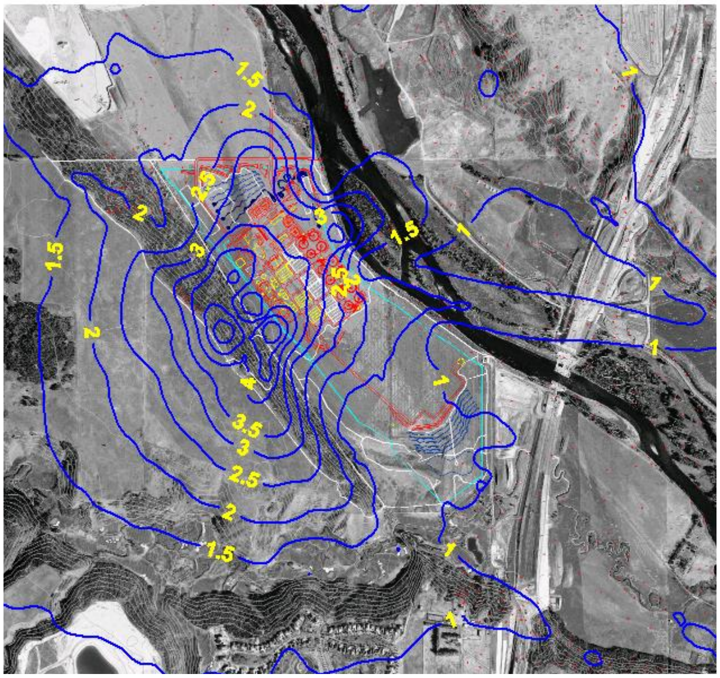

Figure 2: Dispersion modelling example showing the predicted odour concentration "isopleths" around a water recovery facility.

Assessing Current Situation

It is important to identify all the potential critical odour sources, quantify their odour emission rates and quantify the risk of odour emissions due to unusual operating conditions.

- Identify all the odour sources
- Review operational parameters and dimensions of these sources
- Measure the actual extraction rates from sources, compare them to the design
- Identify diurnal or seasonal operational fluctuations
- Estimate fugitive emissions from all sources
- Develop an emissions sampling plan for quantifying odour emissions
- Identify potential operating upsets resulting in increased odour releases
- Assess any available odour complain data and/or data from community surveys

Assessing odours needs to be undertaken in both qualitative and quantitative areas. Qualitative methods include also those means by which residents provide feedback on odour impact, because a resident may be unable to define the odour impact in terms of odour strength. However, these residents are able, when willingly enlisted, to provide high quality feedback on the timing and character of odour impacts and the degree of annoyance they feel about the odours. By keeping records of such feedback over time, a WRF operator can monitor changes in impact and relate these to changes and improvements at the WRF.

Site walks with different facility operators are required for obtaining information about the different odour sources, their history, their relation to the general processes as well as information for the risk analysis for potential operating upset conditions resulting in increased odour releases.

Developing Odour Inventory

Quantitative assessment of odour emissions and odour impacts involves the use of specific odour sampling protocols and odour analysis methods. Sources typically involve point sources (e.g. stacks), area sources (open tanks) and volume sources (e.g. buildings or poorly covered process units). The methods for the sampling odour emissions, particularly for area sources such as open liquid surfaces and aerated area sources such as open biofilters, varies around the world potentially resulting in large differences reported [2, 3]. Well trained personal is required for the execution of the sampling program in close coordination with the facility.

To account for seasonal variations and to capture summer peak loads, it is critical that odour sampling is established and commences in the summer period and runs through the summer months to get a comprehensive data set of the odour emissions (sources and rates).

Often, time and cost constraints do not allow for extensive odour sampling and analysis programs. Field odour olfactometry has been shown to be a very helpful tool to assess odour emissions as an increased number of observations on odour emissions can be obtained on different days, at different times of the day and under different operating conditions. Field monitoring programs inside and outside the facility have been refined over the years as experience grow with better equipment and optimized protocols. The use of field olfactometers can also be integrated at the facility as an operator tool to assess odour emissions on a regular basis or directly after having received an odour complaint from the community located near the facility.

Similarly, when evaluating process changes or potential future odour management options, it is not possible to effectively determine emissions rates for these changes without trials, which is time consuming and expensive. In such circumstances, collection system and/or WRF fate models can be used to predict emissions for different process locations. JACOBS/CH2M has successfully used:

- Process Sewer Models:

Sewer process modeling is used to predict outgassing locations and hydrogen sulfide concentrations for numerous collection systems. The INTERCEPTOR powered by WATS sewer process model for collection systems assists in assessing and reducing odour emissions and/or prolong collection system and WRF headworks life. Prolonging the headworks life can save the WRF millions of dollars.

- Ventilation Models:
Recently improved ventilation models are being used to develop a better understanding of ventilation control strategies. The new ventilation models are being used to provide prediction of air movements that are used for estimating odour emission rates, gas phase hydrogen sulfide concentrations and corrosion rates [4].

- Emission Models:
EPA approved emissions models such as the Bay Area Sewage Total Emissions Model (BASTE). BASTE was originally designed to estimate emission rates of 19 air emission compounds from wastewater treatment plants wastewater treatment processes and has since been improved to estimate over 400 volatile compounds emitted from any wastewater treatment process [5]

- Fugitive Emission Analysis Tools:
The likelihood for fugitive emissions can be determined using a recently developed method by JACOBS/CH2M called odour *Capture Performance* where the performance of a ventilated cover system can be quantified as a function of the local wind conditions [6, 7].

Figure 3: The performance of ventilated cover systems can now be quantified to determine potential fugitive odour emissions.

- Risk Analyses Tools:
The odour inventory typically also includes a risk analyses for potential odour emissions during non-standard operations. Typical potential out-of-optimal range process parameters, equipment reliability and upset likelihood are analyzed based on historical events, single-point of failure analysis and discussions with operators all related to potential odour releases.

Developing Odour Control Alternatives

Once the odour impact criteria have been agreed upon by stakeholders and the odour emissions quantified, development and evaluation of odour control management options can be undertaken. This can consist of a series of iterative dispersion modeling assessments, which determine the odour sources that contribute the most to offsite odour impacts and the effects of various odour control measures or interventions. The assessment will prioritize the odour sources.

The next phase in the assessment is to determine the most appropriate control solutions to be used. The evaluation process should not be based solely on cost, preconceived technology, or standard approaches. Ideally, it will identify and account for the different selection parameters and stakeholders, include some weighting to the factors identified to balance competing needs, consider treatment process changes, and should include a net present worth analysis.

To assess odour control management options, several factors need to be considered:

- Benchmarking operational and housekeeping practices
- Impacts of other processes and operation and maintenance (O&M) efforts
- Potential corrosion and life expectancy of assets with and without odour control measures
- The availability of capital and land, climate and operator capabilities
- Reduction in odour
- Community impact
- Net Present Value
- Ease of implementation
- Compatibility with long terms site requirements

Significant low-cost improvements can often be achieved through improved housekeeping and small operational changes. Examples of these improvements include extending odorous return side streams (e.g. centrate or leachate) to below water level, ensuring that covers are kept closed, replacing broken or corroded covers and missing seals, and preventing the buildup of scum and sludge on surfaces through regular hosing. Installation of level control gates to reduce hydraulic drops has been effective for reducing odours from outlet weirs on primary tanks and Dissolved Air Floatation Thickeners (DAFTs) and is less expensive than installing covers and vapor phase treatment equipment. In addition, efficient aeration systems reduce odours as well as reduces power consumption. Several facilities have reduced odour levels from aeration tanks by switching from coarse to fine bubble aeration systems and, at the same time, substantially reducing power consumption. The results for a retrofitting project in Australia are illustrated in **Table 2**.

Table 2: Odour Emissions from coarse and fine bubble aeration.

	Concentration (OU)		Flux OU/m2/min	
	Fine bubble aeration	**Coarse bubble aeration**	**Fine bubble aeration**	**Coarse bubble aeration**
Pass 1	325	3419	46.5	490
Pass 2	392	2563	56.2	367
Pass 3	277	134	39.7	19.2
Pass 4	273	168	35.1	24.1
Average	**317**	**1571**	**47**	**292**

A large WRF Authority in Pennsylvania was able to defer the vapor phase control strategy of the aeration tanks, because follow up emissions sampling and dispersion modeling after retrofitting with fine bubble aeration systems indicated no offsite impacts.

When evaluating vapor phase control technologies, supplier's claims and performance should be treated with caution and an independent analysis with allowances made for performance variables and equipment deterioration. Odour treatment system performance can deteriorate over time and chemical consumption can be higher than claimed by suppliers. Also, biotechnology has been used successfully used over recent years as a more cost-effective alternative to wet chemical scrubbers and has performed much better than previously, but only when designed and operated properly.

The prevention of odorant formation is a more desirable approach to odour control as it eliminates requiring end-of-the-pipe technologies. Activated Sludge Recycling (ASR) and Oxidized Ammonium Recycling (OAR) are both technologies that present high application potential using readily available plant by-products with a minimum plant upgrading, and relatively low investment and operating costs, contributing to the sustainability and economic efficiency of odour control at wastewater treatment facilities [7]. The results of a trial project in Canada are illustrated in **Figure 4**.

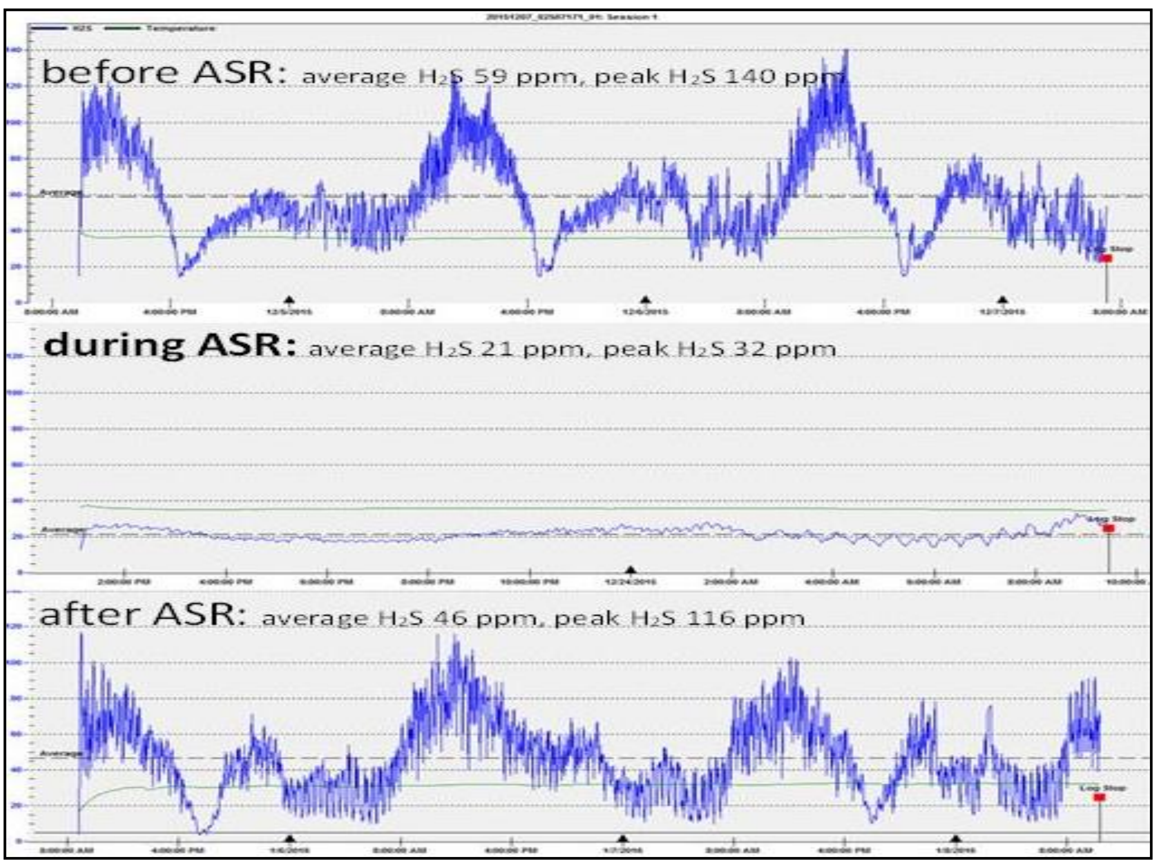

Figure 4: Impact of activated sludge recycling (ASR) on the headspace hydrogen sulfide concentration in the facility inlet channel.

The odour control options analysis should include the evaluation of process changes, process optimizations or replacement of existing process units. Increasing the frequency of emptying and cleaning out settled solids in channels of process units like PSTs or pump stations should be considered and evaluated. It is important to appreciate the interdependence between odour emission rates and operational parameters (and process selection) as part of this exercise.

A structured evaluation to reducing odour is developed for biosolids processes in the Biosolids Odour Reduction Roadmap (BORR) as outlined by WERF [8]. For example, work by JACOBS/CH2M showed that better volatile solids destruction can be achieved with increased digester sludge retention time (SRT). Increasing the digester SRT can be achieved by increasing the digester solids feed concentration, effectively thickening the sludge to a higher concentration. For each 0.5% increase in solids concentration about 8% reduction in total volatile organic sulphur compounds (Total peak S less H_2S-S) from the biosolids can be achieved, reducing the odour from the sludge significantly as shown in **Figure 5**.

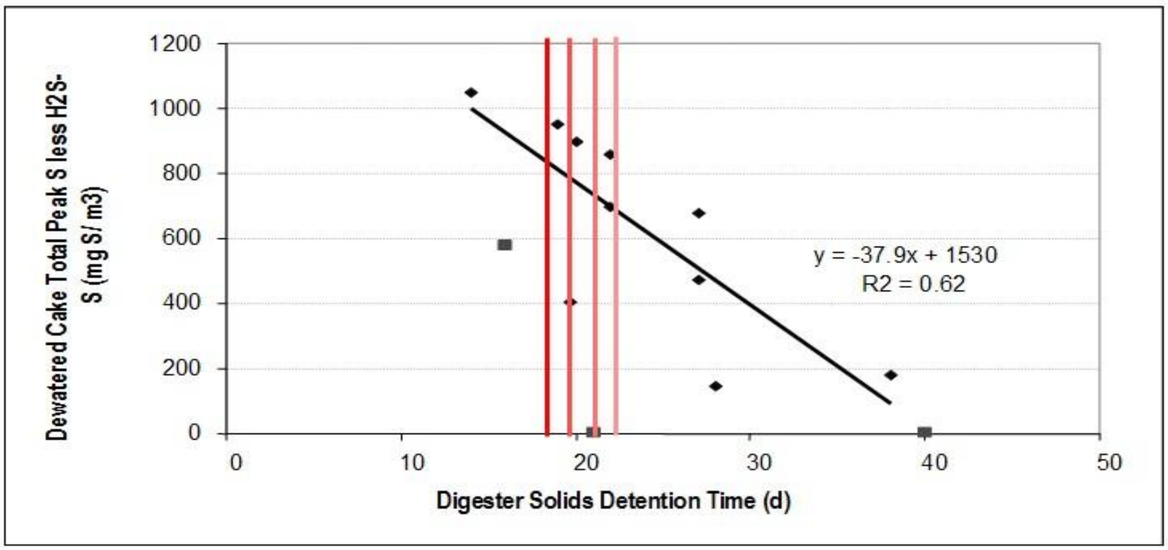

Figure 5: Longer sludge retention time in digesters, due to increased feed solids concentration, resulting in reduced formation of odorous volatile organic sulphur compounds.

Controlling the odours from biosolids has focused on optimizing the digestion and dewatering processes to minimize this odour production. In addition, a method of biologically seeding dewatered biosolids has been developed by JACOBS/CH2M called BORS that significantly reduces the odour emissions by blending aged biosolid cake with fresh cake as it is produced [9]. This will effectively seed the fresh cake with odour reducing microorganisms thereby reducing odour concentrations in the cake much more rapidly than if the cake can age on its own. The results of trials showed that the concentration of different volatile sulfur compound decreased by 50% to 85% depending on the compound as illustrated in **Figure 6**.

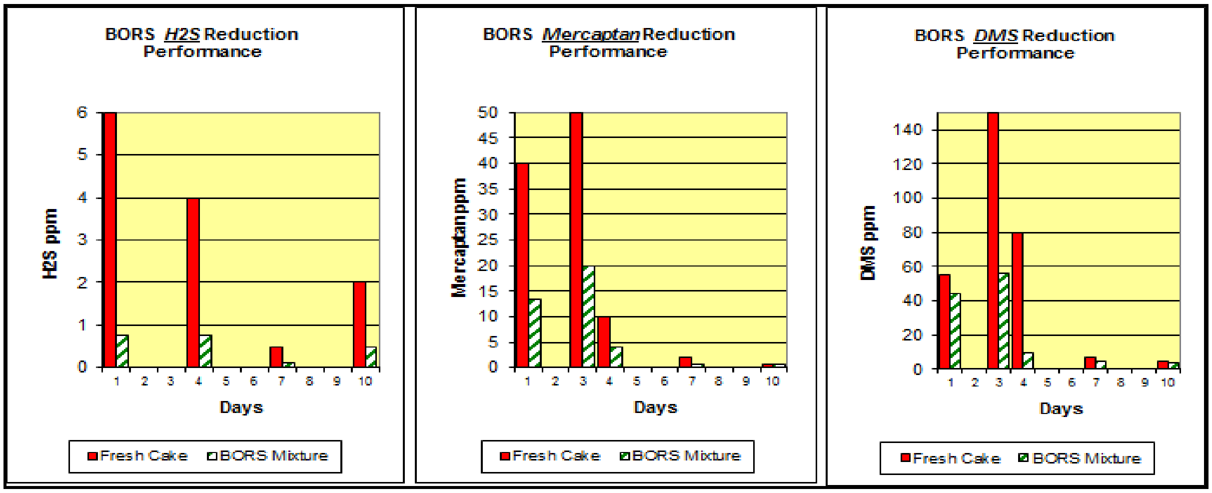

Figure 6: BORS process odorous compound reduction performance results.

Other examples of integrated approaches to reducing odours are the recycling of less odorous air into areas with more concentrated odours while increasing ventilation rates could be explored. Also, potentially the use of buildings, walls and trees to improve dispersion or to reduce visual impact can be, in certain situations, a cost-effective measure that could be considered.

Computational Fluid Dynamics (CFD) have been used to simulate odour dispersion for specific short distance impacts. The aerodynamic effect of building shapes and complex terrain can be predicted more accurately and may complement traditional dispersion modeling methods. CFD modeling can help validate and improve odour mitigation measures such as specially designed odour dispersion walls.

Developing the Odour Control Master Plan

The next step is to document the first steps and develop conclusions, recommendations, and an implementation plan for the facilities involved. Based on the results of the data compilation, analysis and modeling, the recommended operational changes and odour controls should be prioritized in descending order of estimated effectiveness. The prioritized list should then be used to establish an implementation plan, with agreement from all stakeholders. Stakeholder workshops will be held to get to an agreed strategy outlining:

- Critical Works: What needs to be done in the short term to reduce the plants odour contour.
- Important but not Critical Works: Works that will provide important benefits such as, much lower odour impacts, easier impacts assessment; ease of operation, lower odour treatment costs etc.
- Future Works: These will include things that may have to be done in the future, but require further planning or certain triggers before they are implemented.

The" Critical works" and "Important but not Critical Works" will then be developed to a schematic level design and costings further refined to a level that can be used for a business case submission that achieve the best, immediate, short-term, and long-term solutions.

All of the above will then be incorporated into an Odour Master Plan showing the proposed step-wise implementation strategy, required performance and the odour impact contour for each implementation step as well as the decision-making process used. The Master Plan will also provide a longer-term strategy for managing odour impacts in a proactive way, which can be readily communicated to the community.

Implementing Public Outreach

WRFs can be large or small facilities located near or in view of residential areas. In many cases, residents are unaware of the activities occurring within the WRF, and may be suspicious if their first introduction to the plant is a foul odour. Residents often associate the presence of odours with potential human health impacts. These suspicions and concerns can often lead to complaints. Residents who have complained in the past, but have had little or no response from the WRF operator, may be more concerned than would be the case had they been communicated better with.

Community outreach programs can take various forms including having a structured and active complaint response process in place involving residents in odour impact surveys providing facility site tours and information about the WRF to residents and other interested parties, and involving representatives of odour impacted communities in the decision-making process.

An example of where complaints have decreased purely because of an outreach program is at a WRF in the USA. **Figure 7** presents the historical odour complaints. Complaint levels dropped dramatically once the community outreach program commenced. This reduction was prior to the implementation of any actual odour reduction activities, demonstrating that community involvement can partially mitigate odour complaints. Public education and outreach also helps to dispel negative perceptions and ungrounded fears in regard to sewage odours and health effects.

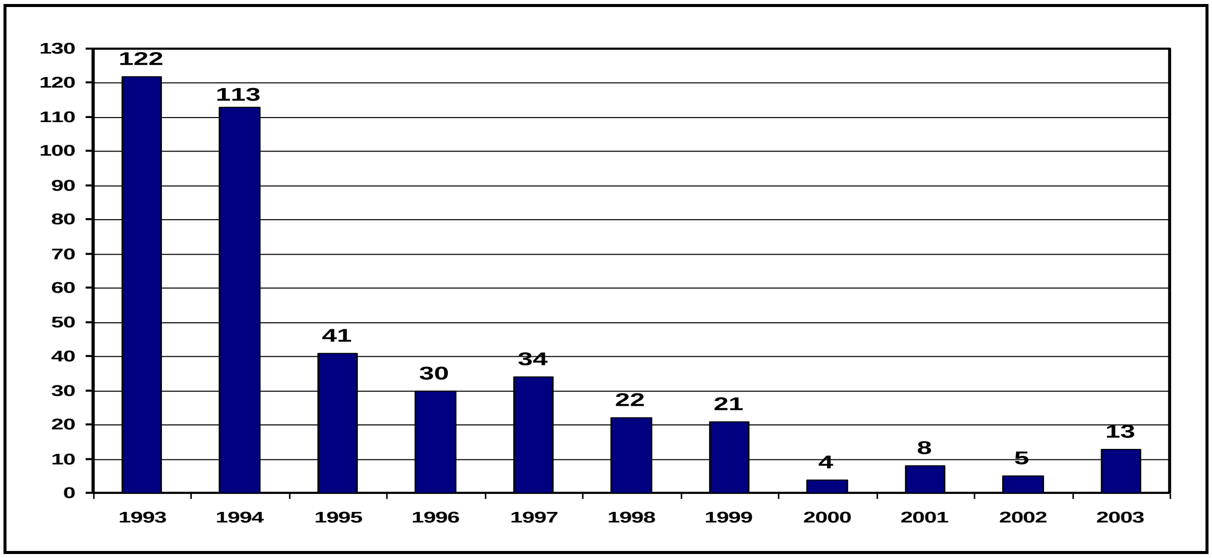

Figure 6: Odour complaints received by year (1993-2003) before and after the implementation of a Community Outreach Program in 1995.

However, community outreach is not an odour reduction tool that can be conducted in isolation. It must be combined with a commitment to a capital improvement program to reduce odour levels. A properly implemented community outreach and education program can provide reasonable timeframes for implementation of odour reduction measures. However, community outreach can turn to community outrage if the agreed odour reduction activities do not occur within the initially communicated timeframe or do not occur at all.

CONCLUSIONS

Although the cost for odour control for the collection and treatment of municipal and industrial wastewaters has increased over recent decades, odour assessment tools have been developed and/or dramatically improved over the last decade as well.

All these tools are now available to be used for Odour Control Master Planning as well as to be used for communication means such as public outreach, community meetings and obtaining internal and external stakeholder support. The discussed Tool Set draws together the aspects of chartering the odour control effort, assessing the current situation, developing detailed alternatives to control odour, and developing the Odour Control Master Plan.

The Odour Control Master Planning Tool Set developed by JACOBS/CH2M has been successfully used over the years to evaluate the issues and obtain endorsement from all stakeholders for a mutually acceptable path forward. Proper evaluation and prioritization of control solutions has helped focus attention on areas that achieve the best, immediate, short-term, and long-term solutions.

References

[1] Dalton, P. (2002) Olfaction, in S. Yamtis amd H. Pashler (eds), *Stevens' Handbook of Experimental Phychology, Vol 1, Sensation and Perception,* 3rd edn. John Wiley and Sons. Inc., New York :691-746.

[2] Cesca, J.; Freeman, T.; Mann, J.; *Odors Ain't Odors. When Is An Odors Offensive?* (2003) Proceedings of the Clean Air Society of Australia and New Zealand National Clean Air Conference: Linking Air Pollution Science, Policy and Management.

[3] Witherspoon, J, Allen, E and Chris Quigley (2002) *Modeling to Assist in Wastewater Collection System Odors and Corrosion Potential Evaluations.* International water Association Conference Singapore.

[4] Ward, M., Hamer, G., McDonald, A., Witherspoon, J., Loh, E., Parker, W. (2011) A Sewer Ventilation Model Applying Conservation of Momentum. Water Science & Technology. 64.6: 1374-1382.

[5] Kepke, J., Schroeter, J., Witherspoon, J., Dinsmore, C. (2003) *The New and Improved BASTE Model for Estimating Odors and VOC Emissions*. Proceedings of the Water Environment Federation, WEFTEC 2003. https://doi.org/10.2175/193864703784756011.

[6] Kraakman, N.J.R, Estrada, J. M., Cowden, S., Cesca, J., Lebrero, R., Muñoz, R. (2016) *Preventing Odor Emissions by Integrated Activated Sludge and Oxidized Ammonium Recycling.* WEFTEC. October 2017. New Orleans, USA.

[7] Kraakman, N.J.R., Cesca, J., Hamer, G., Witherspoon, J. (2016) *Design and Implementation of Air Extraction using the Odor Capture Performance for the Containment of Odors.* WEF specialty conference. March 2016. Milwaukie, USA.

[8] WERF (2008) *Biosolids Processing Modifications For Cake Odor Reduction*. IWAP ISBN: 1-84339-790-0. http://borr.werf.org/.

[9] US patent 7,537,699 B2 and 8,119,003 B1.