Pollution prevention versus wastewater treatment practices for the removal of nonylphenol in Louisville, Colorado

Andrea Stucky

University of Denver University College

Capstone Project for

Master of Applied Science

November 15, 2013

Abstract

Most current municipal water pollution prevention and pre-treatment programs focus solely on industry, but pollution released by individuals, households and small businesses is significant and should be considered. Nonylphenol (NP), a degradate of nonylphenol ethoxylate, is a nonionic surfactant used in industrial and household cleaners. NP is toxic to aquatic life, persistent in the environment and an endocrine disruptor.

Louisville, a small Colorado community, monitors NP effluent levels at its wastewater treatment plant. There are few industrial inputs, so Louisville is an ideal community to implement a residential and small business NP pollution prevention program. By incorporating community-based social marketing strategies, individual behavior change can be achieved to reduce the amount of NP entering the wastewater treatment facility.

Table of Contents

Illustrations

Project Definition

"[M]any of the most vexing environmental problems that remain cannot be resolved without limiting individuals' environmentally destructive choices or at least without spurring individuals to take action that reduce the harm that they cause to the environment" (Johnson 2009, 120). Stephen Johnson, associate dean and professor at Walter F. George School of Law at Mercer University, urges individual action to solve our society's environmental problems. Using his approach to address environmental problems facing our society through individual actions can be used to reduce the presence of nonylphenol in water.

Background

Nonylphenol (NP), a degradation product of nonylphenol ethoxylate, is used in detergents, cleaning supplies, pesticides, paints, some cosmetics and food packaging. NP has gained attention in the recent years due to its toxicity to aquatic life and environmental persistence. Additionally, NP poses a threat to human health due to its endocrine disrupting potential. The U.S. Environmental Protection Agency (EPA) has conducted an alternatives assessment that identifies alternative products that are less toxic to aquatic life and less persistent in the environment. In the U.S. there are few regulations regarding NP's presence in water. The 2010 EPA Action Plan for nonylphenol reveals possible regulatory steps regarding NP. The Action Plan states that amendments could be made for release reporting under the Toxic

Substances Control Act (TSCA) and Emergency Planning Community Right-to-know Act (EPCRA). These proposed regulations only address release reporting, not product bans and use limits.

Problem Statement

Wastewater treatment plants treat water connected to sewer systems. Wastewater treatment removes certain chemicals from water before discharging effluent back into surface water. These facilities are only responsible for removing regulated compounds and are referred to as "end of pipe" treatment methods (Nath 2003). These methods of removing pollutants in wastewater treatment facilities are expensive to install, maintain and upgrade. Alternatively, pollution prevention seeks to reduce the amount of a pollutant entering wastewater by altering behavior to avoid the use of products containing a specified pollutant. This is a "before the pipe" prevention method (Nath 2003). Pollution prevention is more economical, successful, and immediate results for NP removal have been observed, such as the Bismarck, ND case study discussed later in this paper. This project will examine the economics and effectiveness of wastewater treatment and pollution prevention methods for nonylphenol removal in Louisville, Colorado.

Project Foundations

NP ($C_{15}H_{24}O$) is a degradation product of nonylphenol ethoxylates used in nonionic surfactants in industrial and household cleaning supplies (Soares, Guieysse, Jefferson, Cartmell, and Lester 2008). Surfactants reduce the surface tension between two liquids or between a liquid and a solid. NP is an ingredient in detergents, soaps, degreasers, wetting agents, oil lubricants, paints, pesticides, some cosmetics and food packaging materials (Soares et al. 2008; EU 2002). In the U.S. and Canada, 300-400 million pounds per year of NP are used in products (EPA 2010a).

Chemical properties

NP is a xenobiotic (not naturally occurring) compound, characterized as a pale yellow liquid with a phenolic odor (Jie et al. 2012). Its structure contains a phenol ring and a nine-carbon chain (Soares et al. 2008). NP is a hydrophobic compound (log K_{ow} = 4.48), has a low water solubility, is attracted to organic material, and has low mobility (Soares et al. 2008). With a vapor pressure of 2.07×10^{-2} Pa, NP is considered a semi-volatile organic compound (Soares et al. 2008). Wet deposition can transport NP between air and water. NP has a 60-year half-life in sediment and is thus considered environmentally persistent (Soares et al. 2008). NP is "moderately bioaccumulative" in the environment (EPA 2010a). NP can volatize, but it degrades rapidly in air due to hydroxyl radicals. Thus, NP is not persistent in air (EPA 2012). Photolysis from sunlight can reduce NP concentrations in the top layer of surface water (Soares et al. 2008).

Environmental and human health impacts

NP is released by individual households, small businesses, and industrial facilities and enters the wastewater treatment facility where it is not targeted for removal. NP enters the environment primarily through effluent released from wastewater treatment facilities. Direct releases and spills, while representing a smaller percentage than effluent, also contribute to NP's release into the environment. Biomonitoring reveals that NP is found in general population studies and has been detected in breast milk, umbilical cord blood, and urine (EPA 2010a). Because few studies have been conducted on human health impacts of NP, specific daily intake values for NP are uncertain. However, children are at greater risk for NP exposure because they eat and drink more per pound than adults. Additionally, children are exposed to NP from carpet and floor cleaners, because they crawl around on the floor (EPA 2010a).

Potential adverse human health impacts of NP could result due to a low-dose, long-term exposure. While few studies have been conducted on humans, some studies conducted on laboratory rats reveal that NP has potential to cause human health impacts. Humans uptake NP in various ways, including drinking water and eating food which contains NP, and through the use of products that contain NP. Because NP is not targeted for removal from wastewater treatment facilities, humans may be exposed to NP through water intake (EU 2002). Guenther et al. (2002) found that NP was ubiquitous in food and food packaging materials in Germany. Inadvertent ingestion of products such as detergents, cosmetics, and indoor pesticides that contain NP could serve as an additional exposure route for NP in humans. Once NP has entered the human body, it is absorbed in the gastrointestinal tract and distributed throughout the body via blood (EU 2002). NP is excreted through feces and urine (EU 2002).

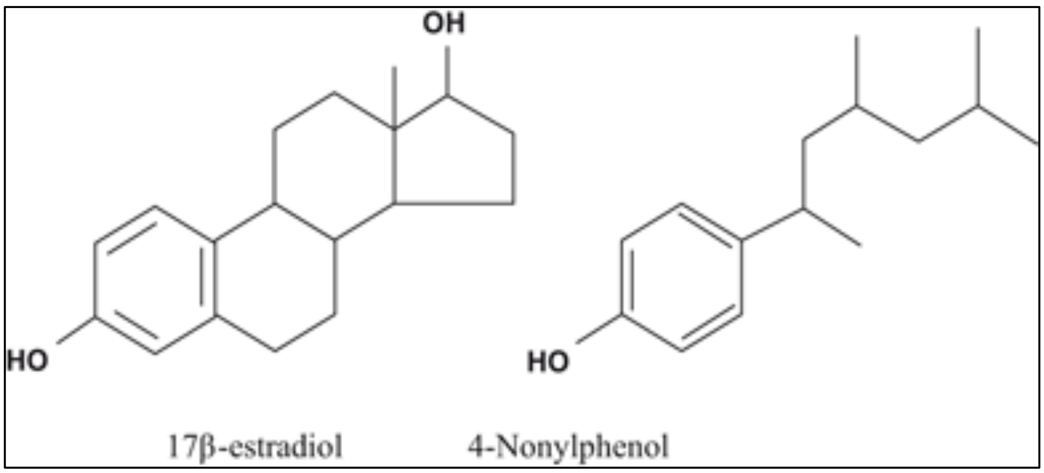

Figure 1. Chemical structures of 17β-estradiol and 4-nonylphenol. *Source*: Jie et al. 2012

While research on human health impacts of NP is limited, studies agree that NP has estrogenic properties (Jie et al. 2012; EPA 2010a; EU 2002). Due to NP’s similar structure to 17β-estradiol, it is considered an endocrine disruptor because NP can bind to estrogen receptor sites (Jie et al. 2012). Figure 1 shows the chemical structure of 17β-estradiol and NP. The similarities in structure allow NP to bind to estrogen receptor sites. Table 1 summarizes additional human health aspects of NP including reproductive impacts, toxicokinetics, corrosivity, neurotoxicity, mutagenicity, and carcinogenicity.

Table 1. Human health aspects of NP

Reproductive Impacts	Timing of vaginal opening
	Ovarian weight
	Sperm/spermatid counts
	Changes in estrous cycle lengths
Toxicokinetics	Absorption occurs in gastrointestinal tract
	Widespread distribution, highest concentrations in fats
	Metabolic pathways include glucuronide and sulfate conjugation
	Excretion through urine and feces
	Insufficient data to determine whether bioaccumulation occurs
Corrosivity	Highly irritating and corrosive to skin and eyes
Neurotoxicity	Adverse effects on brain development; could lead to brain degeneration
Mutagenicity	Biological assays in vivo (on bacteria) and in vitro studies (on mammalian cells) reveal NP not mutagenic
Carcinogenicity	None suspected because NP is not a mutagen

Source: Data from EPA 2009; EPA 2010a; EU 2002; Jie et al. 2003

NP is extremely toxic to aquatic organisms, especially invertebrates. This is significant because aquatic invertebrates represent the base of the aquatic food chain. Correa-Reyes et al. (2007) found that organisms in the first trophic level are able to bioconcentrate NP. Additionally, their research revealed that the bioconcentration of NP could impact the growth of crustaceans (Correa-Reyes et al. 2007). EPA arrived at proposed ambient water quality criteria for NP. For freshwater, EPA suggests 28μg/L for acute (short-term) exposure and 6.6μg/L for chronic (long-term) exposure (EPA 2010a).

Regulatory status of NP

While the U.S. has little regulation regarding the use of NP and its presence in water, other countries have adopted regulations to limit the use of NP in products. In 2010, EPA conducted a study to determine acceptable NP levels in water and is encouraging the laundry industry to participate in a voluntary phase-out. Additionally, EPA has established the Design for the Environment (DfE) Safer Detergents Stewardship Initiative (SDSI). The Action Plan posits future regulation for NP under TSCA and EPCRA. A significant new use rule is proposed under section 5(a) of TSCA and release reporting is proposed under EPCRA Toxic Release Inventory (TRI) (NP and NPE Action Plan Summary 2013). A new use rule requires manufacturers to notify EPA of NP levels in their products. It is important to note that the Action Plan did not mention further regulations addressing NP's presence in water.

The European Union (EU) and Canada have taken stronger stances on NP. In 2003, an EU directive was passed that bans quantities greater than one percent by weight of NP in industrial and domestic products because of its aquatic toxicity and environmental persistence (EU 2003). Canada has acted to regulate NP use in products (EPA 2010a). Additionally, the United

Nations Environment Programme listed NP as a chemical on the Regionally Based Assessment of Persistent Toxic Substances[1] (EPA 2010a).

As a result of the 2010 Action Plan for Nonylphenol by the EPA, the Colorado Department of Public Health and the Environment (CDPHE) decided to require reporting on discharge permits for certain wastewater treatment facilities. CDPHE conducted a reasonable potential analysis for pollutants of concern in effluent, including NP. The analysis consisted of collecting effluent data, influent data, published studies, and wastewater treatment process knowledge. The analysis results concluded that NP could be present in domestic wastewater treatment facility effluent (Janet Kieler, September 27, 2013, e-mail message to author). CDPHE then quantified levels of NP for specific facilities. Each waterway in Colorado is segmented and classified depending upon what is being discharged into the waterway and the ecological importance of that segment. CDPHE requires NP monitoring and reporting on discharge permits for some stream segments along the Front Range.

Alternatives to NP

The DfE Alternatives Assessment for Nonylphenol Ethoxylates (2012) reveals alternatives for nonylphenol that are less toxic to aquatic life and less environmentally persistent. The DfE Alternative Assessment determines

[1] This program assesses threats and damages of specified toxic substances throughout various regions of the world (UNEP 2001).

safer surfactants through assessment of persistence, acute toxicity, chronic toxicity and degradate toxicity to determine whether the compound is a viable alternative to NP. For an alternative to be approved as a safer surfactant under the DfE, it must be less toxic to aquatic wildlife and less persistent in the environment than NP. The alternative must also be comparable in cost and performance to NP-containing detergents (EPA 2010a). Other alkylphenol ethoxylates, excluding octophenol ethoxylates are valid alternatives (EPA 2010a). (Octophenol ethoxylates demonstrated similar environmental persistence and aquatic toxicity to NP.) Alcohol ethoxylates and glucose-based carbohydrate derivatives showed fewer environmental impacts.

In addition to chemical alternatives, strategy alternatives exist to reduce the amount of NP entering wastewater treatment facilities. Reduction in the amount of detergent and soap while laundering and cleaning will reduce the amount of NP entering the environment. Selecting products that do not contain NP or NPE and products that are part of EPA's Safer Surfactants Stewardship Initiative (SDSI) will further reduce NP entering wastewater treatment facilities.

Louisville wastewater treatment plant

Louisville, Colorado is a small town located approximately 25 miles north of Denver and about 6 miles east of Boulder. (*See* Figure 2) The town of Louisville has a population of 18,376 (City of Louisville n.d. a). Few industrial facilities discharge into the Louisville wastewater treatment plant (WWTP). A majority of wastewater influent originates from households and small businesses. Louisville discharges into stream segment COSPBO07b of Coal Creek. Coal Creek flows into Boulder Creek, which eventually flows into the South Platte River. The water quality classifications for the stream segment to which Louisville's effluent discharges are aquatic life 2 warm, recreation E, agriculture (Colorado Water Quality Control Commission 2013).

Figure 2. Map of Louisville
Source: City of Louisville, Boulder County, Colorado, n.d.

Once wastewater arrives at the Louisville WWTP, it flows through pre-treatment consisting of a series of screens to remove large debris and grit, and then through a Parshall Flue and flow-measuring devices (City of Louisville n.d. b). Next, the water enters secondary treatment which consists of extended aeration and application of activated sludge (City of Louisville n.d. b). Before effluent is discharged into Coal Creek, it passes through a UV-light disinfection system. Most effluent is discharged into Coal Creek but a portion is used for irrigation at a nearby sports complex. Sludge and biosolids are removed, aerated, and dried (City of Louisville n.d. b).

Reporting and monitoring for NP

The Federal Clean Water Act addresses health of surface water and the Safe Drinking Water Act addresses standards for drinking water. Neither act specifically addresses NP as a pollutant for monitoring. EPA proposed ambient water quality standards for NP and 40 CFR 136 Appendix B provides guidelines for monitoring NP in effluent. Colorado Water Quality Control Commission (WQCC) Regulation 38 requires that classified stream segments report NP levels in effluent. This requirement applies to most industrial facilities along or near confluence with the South Platte River.

Whole effluent toxicity (WET) testing is used to monitor NP levels in effluent. Fathead minnows and *Ceriodaphnia dubia* are exposed to various effluent concentrations (*Colorado Code of Regulations* 2013). WET testing determines acute (short-term exposure) and chronic (long-term exposure) toxicity of effluent.

Louisville's WWTP has been monitoring and reporting NP since October 2011. The WWTP is most concerned about 4-NP (branched). The highest recorded influent of NP at Louisville WWTP was 40 parts per billion (ppb) (Patrick Farrell, September 30, 2013, e-mail message to the author). Louisville's WWTP does not target for NP removal, but some may be occurring according to Patrick Farrell, Industrial Pretreatment Program at Louisville WWTP, although he did not provide an explanation for that removal. Louisville's WWTP has not implemented NP pollution prevention methods. Without scientifically verifiable data one could assume his data could be low due to his position at Louisville WWTP.

Wastewater treatment technologies for removal of NP

Current wastewater treatment facilities are not suitable or efficient for NP removal (Gao et al. 2011). Additionally, the breakdown of NPE can lead to derivatives of NP that are more toxic than the original NPE. Biological, chemical, and electrochemical removal of NP have been researched, although studies are limited. Biological treatment for NP removal uses bacteria or other microorganisms to remove NP. Biological removal of NP consists of two drawbacks. Some toxic pollutants can alter the way bacteria behave and certain biotic and abiotic factors impact removal rates (Kuramitz et al. 2002; Gao et al. 2011). The biotic and abiotic factors include temperature, light, growth condition, and initial biomass concentration (Gao et al. 2011). Chemical removal of NP involves adding oxidizing reagents.

Removal through oxidative methods requires large quantities of reacting agents, such as ozone, chlorine dioxide or hydrogen peroxide (Kuramitz et al. 2002). A study conducted by Ciorba et al. (2002) concluded that NPE (4-ethoxylate molecules) had only 40-80 percent removal rates through electrochemical-generated coagulants. Table 2 summarizes results from a study conducted by EPA to determine the effectiveness of 4-NP removal at wastewater treatment plants.

Table 2. WWTP removal efficiencies for 4-NP

WWTP removal method	Average removal percent efficiency	Number of WWTP included in study
Activated sludge	78	10
Denitrification	91	4
Nitrification	76	6
Chlorine disinfection	73	8

Source: EPA 2010b

Cost and effectiveness of wastewater treatment removal of NP

Numerous technologies and combinations of various strategies are efficient in removing endocrine disrupting compounds from drinking water. However, high organic carbon levels in effluent make these technologies inefficient and increase the cost of removing endocrine disrupting compounds in wastewater (Minnesota Water Sustainability Framework 2011). There are no well-established treatment technologies or strategies for removing endocrine disrupting compounds from wastewater (Minnesota Water Sustainability Framework 2011). As revealed in Table 2, wastewater treatment does not necessarily remove all NP from effluent. Additionally there are trade-offs for various methods of wastewater removal of NP. One tradeoff is cost. In public comments on proposed NP rulemaking, Colorado Springs Utilities estimated spending over $20,000 for NP monitoring and analysis in 2010 (Colorado Water Quality Control Commission 2010).

Pollution prevention

In general terms, current environmental regulations and legislation focus on industrial inputs of pollution with no emphasis on individual behaviors (Kennedy 2010; Johnson 2009). Concerning NP, proposed actions focus solely on addressing industrial inputs. In a 2010 rebuttal statement to proposed NP regulations, the City of Colorado Springs and Colorado Springs Utilities stated that residential sources of NP were significant contributors to NP entering its WWTP (Colorado Water Quality Control Commission 2010). Colorado Springs Utilities provides education and product substitution information for industrial sources of NP. The statement did not include any actions by Colorado Springs Utilities to address NP release from residential sources. Furthermore, Colorado Springs Utilities insists that without a product ban, NP will remain in wastewater (Colorado Water Quality Control Commission 2010).

Pollution prevention practices seek to prevent the release of a pollutant before it enters wastewater. To prevent pollution, education is important to informing industry and individuals about health and environmental impacts. Community-based social marketing (CBSM), which will be discussed further, provides an effective strategy to translate education into behavior change. In Louisville, households and small businesses account for most of the influent entering the WWTP. While there are few industrial inputs of NP into Louisville WWTP, hotels, motels, laundry facilities, and car and truck washes could contribute to the presence of NP in influent.

Challenges. Similar to wastewater treatment removal of NP, pollution prevention of NP has challenges that must be considered. The underlying theme of pollution prevention is changing people's behaviors, which draws on principles from behavioral psychology. Effective pollution prevention programs require cooperation from pollution source inputs. In the case of NP reduction on an individual level, nonpoint source pollution has numerous potential NP inputs. Since there are few regulations regarding NP and NP is not monitored at all WWTPs, it can be difficult to convince the NP sources of the importance of NP pollution prevention. Research suggests that only providing awareness and understanding of an environmental problem does not change behavior. Rather, implementation of communication, information, prompts or reminders, commitments, and norms lead to behavior change (Smith 2005; Mckenzie-Mohr 2011).

Pollution prevention from nonpoint sources poses another challenge, that of convincing small polluters that their contributions can have an accumulative presence of NP in effluent. Many households can contribute small amounts of a pollutant into wastewater. While the amount of pollutant released may seem inconsequential, cumulative effects can be seen in the environment.

Scientific research results regarding water pollutants often contain complicated language. One challenge is to explain these complex subjects with more simple terminology. Translating scientific research into layman terms will allow the public to understand those research results. Citizens will likely be more interested in research findings and be more inclined to take action.

Cost and effectiveness of pollution prevention: Bismarck, North Dakota case study. In 2011, Bismarck, North Dakota was failing WET tests for NP. Bismarck's WWTP is equipped with trickle filters which do not remove NP from wastewater. To address NP levels in effluent, the WWTP pollution pre-treatment department approached industry, mainly hotels and laundry facilities, about their use of NP. Bismarck's WWTP approach to industry was to communicate the benefits of switching to NP-free detergents, which results in a cleaner environment. The WWTP made the issue of failing WET tests for NP applicable to workers in those industries by emphasizing river health when talking to businesses. As stated earlier, NP is toxic to aquatic biota, so the pretreatment program emphasized river health when talking to industry. Many hotel and laundry employees fish or participate in other recreational activities that rely heavily on healthy rivers. Hotels in Bismarck were receptive to NP alternatives and began using them (Dean Woehl, September 30, 2013, telephone conversation with author). Additionally, the WWTP did not require changes to implement NP alternatives, but rather recommended changes. After approaching industry the WWTP saw "almost immediate" changes in WET tests for NP (Dean Woehl, September 30, 2013, telephone conversation with author). Furthermore, an estimated 90 percent of Bismarck's industrial businesses switched to NP-free detergents and continue to use NP alternatives (Dean Woehl, September 30, 2013, telephone conversation with author).

Engaging stakeholders. Pollution prevention requires the gathering of stakeholders to discuss potential impacts and solutions. Within the body of stakeholders, different interest groups are able to discuss how pollution prevention will impact them. Additionally, the engagement of stakeholders can lead to the identification of barriers and discussion of possible solutions that overcome the barriers. In the instance of Bismarck, ND, no regulatory framework was required. Thus, their program successfully relied on voluntary compliance and therefore avoided issuing and enforcing regulations directed to industrial NP polluters.

Comparison of wastewater treatment and pollution prevention for NP removal

Wastewater treatment removal of NP does not in itself rely on community support for NP usage reduction. For NP removal at wastewater treatment facilities, people are not required to change behavior. Additionally, citizens are likely unaware of the impacts NP poses to human and environmental health as a result of using NP-containing products. Wastewater treatment removal of NP is expensive to install and maintain. Costs for inputs such as reactive agents or bacteria for NP removal must be considered. Constraints such as temperature, time, and light could also impact costs and efficacy of NP removal techniques. Table 2 reveals that of the four processes studied for 4-NP removal from wastewater treatment facilities, no process removes all NP from effluent. Research studies suggest that there is not a cost-effective way to remove endocrine disrupting compounds from wastewater effluent due to high organic carbon content in wastewater. Given current technology, wastewater treatment removal of NP is not a viable solution.

The pollution prevention ("before the pipe") approach to NP removal aims to prevent NP from entering wastewater and the environment. Pollution prevention involves changing behaviors to create new norms that foster a desired action. Behavior change and new norms can be achieved through the use of alternative strategies and alternative chemicals. The cost inputs for a pollution prevention program include the cost to develop a community-based social marketing program to target NP reduction. Pollution prevention strategies engage stakeholders, which allows for discussion of impacts, barriers, and solutions to pollution problems. Pollution prevention is a long-term, sustainable approach because it seeks to change norms that foster behaviors which prevent NP pollution from entering wastewater treatment facilities.

From a viable process and cost standpoint, pollution prevention appears to be the better option to reduce the amount of NP entering the environment. Without implementation of individual responsibility and action, many environmental problems that face society will not be resolved (Johnson 2009). Current pollution prevention seeks to target industrial users of NP and tends to be more community-based than wastewater treatment removal of NP. As evidenced by the Bismarck, North Dakota case study, pollution prevention delivers immediate, effective results and has potential for long-term success through behavioral modification.

Project Solution

To reduce the amount of NP entering wastewater treatment at the individual level, a pollution prevention program focused on the individual is a viable option. This section addresses the proposed approach and solution to implement a pollution prevention program for NP in Louisville, Colorado.

Approach

Louisville's WWTP is currently not exceeding reporting limits for NP. Although the highest reported influent level for NP was 40 ppb, not an alarmingly high level given current CDPHE guidelines, the implementation of a residential pollution prevention program in Louisville would decrease the amount of NP entering the WWTP and discharged into the local environment.

Developing and implementing new regulations can take significant time and resources, so adopting a voluntary approach to pollution prevention would result in more-timely, agreed upon solutions in a less politicized atmosphere. NP release in Louisville is considered nonpoint source pollution due to the numerous inputs into wastewater. Since NP is a nonpoint source, it is impractical to enforce regulations against each individual polluter. Additionally, each household probably does not release a significant amount of NP. But cumulative impacts of NP from numerous, small inputs can result in environmental degradation.

Coal Creek flows through Louisville and provides various recreational activities. Louisville residents use Coal Creek and its riparian area for recreational activities. Linking NP pollution to the environmental health of Coal Creek and its riparian area could convince residents to change their behavior regarding NP use and release.

***Community-based social marketing*.** With roots in environmental psychology, community-based social marketing (CBSM) is a research-tested method for behavior change. Many environmental problems are the result of repetitive actions as opposed to one-time events that cause harm to the environment (McKenzie-Mohr 2011). CBSM provides strategies to alter behaviors and shift norms to encourage repetitive actions. Convenience and economics are typically important to customers when behavior change is being targeted (Smith 2005).

***The five steps of CBSM*.** The first step of CBSM is to select behaviors. These behaviors should be non-divisible and end-state. Non-divisible refers to behaviors that cannot be broken down into other activities that would require other behaviors (McKenzie-Mohr 2011). End-state behaviors result in a desired outcome (McKenzie-Mohr 2011). Using NP as an example, the end-state behavior would be to *use* NP-free products, not just to buy NP-free products. Once non-divisible, end-state behaviors have been selected, conduct an assessment of their impact, probability and penetration, and select behaviors that have the highest potential to affect a desired outcome (McKenzie-Mohr 2011). Impact, probability and penetration involves collecting information and research to determine which behaviors will have the most impact, the probability that target audience will engage in selected behavior, and whether the target audience is already engaged in the selected behavior (McKenzie-Mohr 2011).

Identifying barriers and benefits is the second step in developing a CBSM program. This step is important for program effectiveness because it determines the inhibiting factors that prevent the public from participating in the targeted behavior (McKenzie-Mohr 2011). Conducting surveys and talking with residents will help to identify barriers to carrying out a desired behavior (McKenzie-Mohr 2011). This step provides opportunity to assess all barriers and benefits associated with a selected behavior change.

The third step consists of developing strategies to overcome the barriers and encourage benefits from behavior change. Commitments, prompts and norms are strategies to promote behavior change. Research has shown that commitments increase the likelihood that an individual will change a selected behavior. When individuals make a commitment to participate in changing a selected behavior, they shift their attitudes to be in line with the commitment they made (Lokhorst et al. 2011). Small actions and short-term commitments lead to long-term "self-directed" behavior change (Kennedy 2010; Lokhorst et al. 2011). Individuals want to be consistent or appear to others to be consistent (Kennedy 2010; Lokhorst et al. 2011). After commitments are made, participants persuade themselves that the new behavior and commitment are worthwhile (Lokhorst et al. 2011). Commitment can lead to internalized attitudes that create behaviors which are "motivated by personal, durable feeling and behaviors" (Lokhorst et al. 2011, 24).

Prompts are visual or auditory aids that act as reminders for participants to engage in a specific activity or behavior (McKenzie-Mohr 2011). For prompts to be beneficial, they should be placed or used where the desired behavior occurs. For a NP CBSM program, prompts, including signs that read "Protect river health by using NP-free laundry detergent and cleaning supplies", should be placed in laundry rooms and under sinks where detergents and cleaning supplies are located. Additionally, prompts could be located in stores throughout the laundry and cleaning departments advertising NP-free products.

Norms are socially-accepted behaviors. People often act how those around them act (McKenzie-Mohr 2011). By shifting social norms toward the desired selected behavior, the new norm will encourage others to engage in desired behavior. By internalizing the norm, people feel that they "should" engage in the behavior (McKenzie-Mohr 2011). Commitment and prompts help shift the social norms to favor targeted behavior.

The fourth step in developing a CBSM program is piloting. This step involves designing and implementing a small-scale program that uses the same approaches as the full-scale program. By conducting a pilot program, problems that would cause a broad-scale implementation to be unsuccessful can be identified and addressed (McKenzie-Mohr 2011). The pilot program is revised until it is effective and expandable to a broad-scale implementation (McKenzie-Mohr 2011).

Broad-scale implementation is the final step in developing a CBSM program to target behavior change. Once the pilot program has been modified and proven effective, implement a large-scale plan. It is important to collect baseline information and observations that show impacts as a result of behavior change (McKenzie-Mohr 2011). It is important to provide feedback. McKenzie-Mohr (2011) suggests that providing information to a community about a successful program reinforces behavior change.

Stakeholder engagement. Stakeholders should be included in all steps of a CBSM program. Engaging stakeholders brings all interested parties to the table and aids in carrying out pilot and broad scale implementations of the program. For an NP-reduction CBSM program interested Louisville stakeholders include: Louisville's WWTP, Louisville's Sustainability Advisory Board, residents, small and local businesses, outdoor and environmental groups with interest in stream health, mom groups and parents of toddlers and small children.

Recommended Solution

The recommended solution to reduce NP entering wastewater in Louisville, is to implement a pollution prevention program that addresses the five steps of community-based social marketing. Additionally, ensuring that the environmental and health impacts of NP are applicable to the individual is important in creating a successful pollution prevention program.

Discussion and Analysis

As a stakeholder, Louisville WWTP should provide data and support the idea of upstream prevention practices to avoid its costs of technological removal of NP. It is in Louisville WWTP's interest to cooperate with a CBSM program by providing NP monitoring data to convey program success to the community. Additionally, a proven success with a CBSM pollution prevention program would provide the framework and experience necessary to address future pollution prevention programs involving other pollutants. By reducing current NP levels through a residential pollution prevention program, Louisville could experience growth without fear of exceeding NP limits.

Pollution prevention methods should be of the highest priority for reduction of NP entering the environment. Due to its cost-effectiveness, success, immediacy, and community-based approach, removal of NP entering wastewater can be achieved through pollution prevention methods. Current pre-treatment practices focus on industry, but little emphasis has been placed on the individual’s usage. The logical next step to tackle remaining NP pollution would be to address residential and small business nonpoint sources of that pollution.

CBSM is the ideal strategy because it is a community-based, integrated approach to behavioral change. Based on Bismarck, North Dakota’s strategy to reduce industrial NP pollution, a residential pollution prevention program is an effective method for Louisville to implement to reduce NP entering wastewater. CBSM’s focus on individual behavior change to create new norms will encourage individuals to take responsibility for environmental degradation. Because economic and convenience factors are addressed in the CBSM approach, barriers are identified and considered in project design. Community involvement is an integral component.

Conclusion

Bismarck, North Dakota's strategy to reduce industrial NP pollution proves that pollution prevention methods are successful. Pollution prevention emphasizes consumption reduction of NP, which results in a reduction of NP in discharge. A cooperative, voluntary approach does not rely on the creation and enforcement of new legislation proposing regulations. Additionally, the pollution prevention program in Bismarck, North Dakota laid a framework for industrial pollution prevention that would likely facilitate future cooperation in programs to reduce pollution from other pollutants.

Addressing environmental problems through individual actions, as Johnson states in the opening comment, is likely the way to solve many of our society's current and future environmental issues. Pollution reduction at the source saves potential costly investment by wastewater treatment facilities for equipment, supplies, and maintenance. CBSM relies on voluntary compliance among people as opposed to regulatory action, which can be a politicized event. The proposed residential pollution prevention program in Louisville, Colorado does not view the environmental issue of NP pollution as a set of regulations; rather it calls on community effort to solve a local, environmental problem. Pollution is an individual responsibility and CBSM is an ideal approach to addressing individual pollution prevention.

References

Ciorba, G. A., C. Radovan, I. Vlaicu, and S. Masu. 2002. Removal of nonylphenol ethoxylates by electrochemically-generated coagulants. *Journal of Applied Electrochemistry* 32, no. 5 (May): 561-567.

City of Louisville. About Louisville. http://www.louisvilleco.gov/VISITING/AboutLouisville/tabid/196/Default.aspx (accessed October 6-November 13, 2013).

City of Lousiville. Wastewater Treament Facility. http://www.louisvilleco.gov/Portals/0/Public Works/wwtpbrochure.pdf (accessed September 22, 2013).

City of Louisville, Boulder County, Colorado. Regional map. http://www.louisvillecolorado.biz/datapages/regionalmap.htm (accessed November 15, 2013).

Colorado Water Quality Control Commission. *Colorado Code of Regulations* 2013. Title 5, sec. 1002-38.

Colorado Water Quality Control Commission. 2010. *Rebuttal Statement of the City of Colorado Springs and Colorado Springs Utilities: In the Matter of the Adoption of Revisions to the Basic Statrds and Methodologies for Surface Water, Regulation #31, (5 CCR 1002-31)*. Denver.

Colorado Water Quality Control Commission. 2013. *Regulation #38 Stream Classifications and Water Quality Standards*.

Correa-Reyes, Gabriel, Maria Teresa Viana, Facundo J. Marquez-Rocha, Alexi F. Licea, Elizabeth Ponce, and Rafael Vasquez-Duhalt. 2007. *Chemosphere* 68, no. 4 (June): 662-670.

European Union. 2002. European Union Risk Assessment Report. 4-Nonylphenol (Branched) and Nonylphenol. 2nd Priority List, vol. 10.

European Union. 2003. *Directive 2003/53/EC of the European Parliament and of the Council*. Luxembourg: European Union.

Farrell, Patrick. 2013. E-mail message to author. September 30.

Gao, Q.T., Y.S. Wong, and N.F.Y. Tam. 2011. Removal and biodegradation of nonylphenol by different *Chlorella* species. *Marine Pollution Bulletin* 63, no. 5-12:445-451.

Guenther, Klaus, Volkmar Heinke, Bjoern Thiele, Einhard Kleist, Hartmut Prast, and Torsten Raecker. 2002. Endocrine disrupting nonylphenols are ubiquitous in food. *Environmental Science and Technology* 36, no. 8:1676-1680.

Jie, Xu, Li JianMei, Feng Zheng, Gong Lei, Zhang Biao, and Yu Jie. 2013. Neurotoxic effects of nonylphenol: A review. *Wiener klinische Wochenschrift* 125, no. 3-4 (February): 61-70.

Johnson, Stephen M. 2009. Is religion the environment's last best hope? Targeting change in individual behavior through personal norm activation. *Journal of Environmental Law and Litigation* 24, no. 1: 119-164.

Kennedy, Amanda L. 2010. Using community-based social marketing techniques to enhance environmental regulation. *Sustainability* 2, no. 4:1138-1160.

Kieler, Janet. 2013. E-mail message to author. September 27.

Kuramitz, Hideki, Jun Saitoh, Toshiaki Hattori, and Shunitz Tanaka. 2002. Electrochemical removal of *p*-nonylphenol from dilute solutions using a carbon fiber anode. *Water Research* 36, no. 13 (July): 3323-3329.

Lokhurst, Anne Marike, Carol Werner, Henk Staats, Eric van Dijk, and Jeff L. Gale. 2011. Commitment and behavior change: A meta-analysis and critical review of commitment-making strategies in environmental research. *Environment and Behavior* 45, no. 1: 3-34.

Mckenzie-Mohr, Doug. 2011. *Fostering sustainability behavior: An introduction to community-based social marketing*. 3rd ed. Gabriola, B.C.: New Society Publishers.

Minnesota Water Sustainability Framework. 2011. *Water treatment best practices*.

Nath, Bhaskar. 2003. Education for sustainable development: The Johannesburg summit and beyond. *Environment, Development and Sustainability* 5, no 1-2:231-254.

Smith, John. 2005. Community-based social marketing. *Solid Waste and Recycling* 10, no. 2 (April/May): 24-25.

Soares, A., B. Guieysse, B. Jefferson, E. Cartmell, and J.N. Lester. 2008. Nonylphenol in the environment: A critical review on occurrence, fate, toxicity and treatment in wastewaters. *Environment International* 34, no. 7 (October): 1033-1049.

United Nations Environmental Programme. 2001. *Regionaly-based Assessment of Persistent Toxic Substances: Desk Evaluation*, by Susanne Bech. Evaluation and Oversight Unit.

U.S. Environmental Protection Agency. 2009. *Screening-level Hazard Characterization: Alkylphenols Category*.

U.S. Environmental Protection Agency. 2010a. *Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan*.

U.S. Environmental Protection Agency. 2010b. *Treating Contaminants of Emerging Concern: A Literature Review Database*. Prepared by the Office of Water: Engineering and Analysis Division. Washington, D.C.

U.S. Environmental Protection Agency. Design for the Environment. 2012. *DfE Alternatives Assessment for Nonylphenol Exthoxylates*.

Woehl, Dean. 20103. Telephone conversation with author. September 30.