BOWSER WASTEWATER TREATMENT SUBMISSION TO FEDERAL AND PROVINCIAL AUTHORITIES REGARDING HEALTH AND ENVIRONMENTAL RISKS

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EXECUTIVE SUMMARY

There is increasing worldwide concern about the risks of discharging effluent from inadequate conventional wastewater treatment systems (WWTS) for the ocean environment, sea life and human health. Unfortunately wastewater treatment inadequacies are often driven by rather static regulations that are slow to adapt, and exhibit a failure to recognize the risks associated with a number of contaminants. Health and government agencies deal with them incompletely during community planning and real estate development activity. This often includes less than full community consultation. Such has been the case in Bowser BC, leaving the community with a proposed system that includes a number of risks that are not addressed.The conventional sequence batch reactor (SBR) and UV light system proposed for Bowser will not effectively deal with a range of viruses, certain bacteria, some parasites, microplastics and an ever increasing number of emerging contaminants.

- There are large numbers of viruses discharged into wastewater, many are resistant to UV light treatment such as adeno and rotaviruses and many have unknown pathogenicity. Norovirus presents particular risks in a shellfish harvesting area because of low dose required for infection, difficulties in detection, uncertainties re ocean survival time, genetic diversity and bioaccumulation in shellfish. There have been many outbreaks of Norovirus infections and shellfish closures have been necessary due to contamination.
- Despite the effectiveness of UV light against many bacteria there is variation in response caused by the differing genetic makeup of the organisms. And DNA repair mechanisms can lead to reactivation following UV light treatment. There is also evidence that the WWTS environment encourages gene transfer and promotes the development of antibiotic resistance. Various strains of Vibrio which cause serious infections and which are naturally found in the oceans are often found in wastewater. Although sensitive to UV light, their presence is not monitored and coliform counts are a poor proxy for assessing contamination of wastewater by them.
- It has also been reported that both viruses and bacteria can bind to sediments where survival is prolonged and from where they can be subsequently released into the water above during turbulent suspension and mixing.
- Cryptosporidium and Giardia are found in wastewater, they present an infectious risk and they are very resistant to UV light, requiring other forms of disinfection to assure their elimination.

- Microplastics are ubiquitous in the ocean environment and the level has reached crisis proportions. Wastewater is one source. They are inadvertently consumed up the food chain from for example zooplankton to shellfish to a broad range of sea life. They have an adverse impact on their health as shown by adverse metabolic effects in laboratory animals and they can serve as vectors for chemical contaminants and bacteria which adhere to them. The role of microplastics in human health is yet to be determined but there is no doubt about their presence in human tissues. The United Nations has expressed concern about their potential risk to human health. They are not removed by conventional wastewater treatment such as that proposed for Bowser.
- While more research is needed on the adverse human health effects of emerging ocean contaminants such as biopharmaceuticals and various chemicals, it is clear that they have adverse effects on sea life such as on their reproduction, endocrine function, behaviour and survival. There is also increasing evidence of their teratogenicity, mutagenicity and carcinogenicity. There are increasing numbers of these contaminants found in wastewater and conventional WWTS do not remove them.
- There is extensive evidence of progressive degradation of the Salish Sea, with one researcher (Professor Leah Bendell, Marine Ecology and Ecotoxicology, SFU) describing the situation as grim and getting grimmer. Various events over the years testify to this. Clearly this is the result of various global influences. However the expansion of domestic sewage discharges along with the expansion of many contaminants has led in part to this degradation. We need a very cautious approach to aquatic management for the protection of our ecosystems. This includes a refusal to discharge wastewater from Bowser into the Baynes Sound, an eco-sensitive part of the Salish Sea.

The risks from this large variety of contaminants for sea life, for further degradation of the Salish Sea, and for human health, are significant. **This means that ocean discharge proximal to a large shellfish cultivation and harvesting area and immediately adjacent to a busy beach recreational area, particularly considering the availability of alternatives, is unconscionable.**

Rather than discharge into the sea, the community of Bowser strongly prefers a land based system of disposal such as a constructed wetlands with the reuse of wastewater, a strategy being pursued by many internationally. And there are some local examples of where this approach has either been implemented or is under consideration. If this is not possible and if sea discharge is to occur, as a minimum a multilayered multifaceted contaminant removal process should be undertaken. Technologies are available to achieve this. The Bowser community asks for support for its position from Federal and Provincial Authorities as well as supporting the establishment of an integrated governance and policy setting mechanism to assure the promulgation of evidence based policies for the protection of the Salish Sea and Baynes Sound.

INTRODUCTION

The purpose of this submission is to request Federal and Provincial Authorities, in the interests of health and the environment, to support the position of the majority of the people of Bowser in their quest for a safe, modern and effective land based wastewater treatment and disposal system. The community strongly holds the view that we must in 2018 move past a proposed basic traditional mechanism for wastewater treatment with discharge into the sea, the effectiveness of which is limited to reductions in BOD (biochemical oxygen demand), TSS (total suspended solids) and coliform counts. The system should be designed to deal more effectively with a number of prevailing and developing risks which includes emerging contaminants, a wide variety of disease producing viruses, other pathogens and microplastics (62,65). This is a position supported by Dr. Nicholas Ashbolt, Professor, School of Public Health, University of Alberta who has done extensive research on this subject and has collaborated internationally on wastewater systems. He is among many who on a global basis share the same opinion.

Because of the increasing incidence of shellfish diseases as well as human health concerns there have been a number of closures of shellfish cultivation/harvesting areas (40,49,54,66,73,74).The Salish Sea has been the recipient of wastes from multiple sources both industrial and domestic harmful diverse contaminants that must be dealt with in any wastewater treatment system. The community of Bowser does not wish to add to this by discharging into the Salish Sea. The goal of the community is to stop ocean discharge and pursue a much preferred and safer land based system. The following describes the community of Bowser, the proposed system, various health and environmental risks and a proposed better system to mitigate these risks.

THE BOWSER COMMUNITY

Bowser is located within Area H, an area within the jurisdiction of the Regional District of Nanaimo (RDN). It encompasses 15.5 km of coastline extending from just east of Qualicum Bay to Deep Bay in the west. With a population of 1700, it is located about 30 km east of Qualicum Beach and approximately mid way between Nanaimo and Courtney /Comox on Vancouver Island. It is a significant part of what is referred to as ‘’Lighthouse Country’’. This community borders on the Strait of Georgia, and on that part of the coast designated as the Salish Sea, a sea which has slow moving deep water and where flushing is poor. It is directly adjacent to Baynes Sound. The latter is a body of water between Vancouver Island and the islands of Denman and Hornby extending from Courtenay/Comox in the west to the tips of Denman and Hornby in the east. The waters of Baynes Sound are contiguous with those of many other communities which border it.

The Bowser nearshore is biologically very productive and was used by First Nations for over 3000 years to provide food through the use of fish traps along the shore. Annually there is also a very high spring/summer congregation of eagles feeding on small forage fish that spawn on the local beaches and stay for several months as they mature. The annual spawning of herring from Nanaimo to Comox represents 50% of all herring spawning in BC, and it occurs each March/April along the shores of Bowser supporting a very active annual fishery and bringing many predators. Herring attach eggs to vegetation such as seaweed and grasses which grow along local shores below the high tide level. Other forage fish important in the aquatic food chain also spawn in the intertidal regions of the beaches in this area. In addition this is an ocean contact recreation area for humans that is used in all seasons and includes swimming, snorkeling and winter windsurfing in the vicinity of the proposed outfall. And shellfish gathering is widespread. First Nations harvest herring eggs attached to vegetation among other traditional food sources.

Baynes Sound is also home to a well known robust and expanding shellfish industry, which includes the cultivation of filter feeding oysters, scallops, clams, geoducks and mussels, representing about 50% of BC production. **90% of the Baynes Sound coastline is under shellfish industry tenure**! The shellfish products of the Sound are shipped worldwide. Prawns and shrimp have also been harvested. The cultivated and harvested organisms are consumed through domestic and international markets.

RDN PROPOSED WASTEWATER TREATMENT FOR BOWSER

The proposed wastewater treatment system for Bowser involves the installation of a conventional sequence batch reactor (SBR) of a similar design originally patented in 1913 (22,69). This is a fill and draw activated sludge secondary treatment system. It is carried out in batches and involves five stages through which some undesirable components are treated and removed and where clarification/settling is achieved through the time controlled sequence of stages. This is a 4 hour cycle SBR with little time for nutrient reduction or for pathogen die off. The effluent will be subject to disinfection using Ultraviolet light in a dose of 60-90 mJ/cm2 and then discharged into Baynes Sound 2350 meters from shore and close to an established scallop farm lease and in the vicinity of multiple shellfish farms and foreshore intertidal and subtidal shellfish zones. The system will be developed in phases, the first to serve 600 people in the main part of Bowser village in connection with a real estate development plan. The current design includes drawings for additional SBRs to accommodate consolidation with other developments or existing communities. It is very likely that Bowser will become the sewage hub for all of the Lighthouse area as the RDNs #5 pollution control centre. With the low quality of planned effluent treatment cumulative health impacts within these shellfish waters are certain.

Sequence batch reactors were developed early in the 20th century and improved in the 50s and 60s (19). But in view of emerging risks, the backdrop of a declining Salish Sea and in the immediate presence of a sensitive important shellfish industry, this must be considered old and inappropriately applied technology. While SBRs have been shown to work reasonably well to reduce BOD, TSS, and with the use of UV light reduces coliform counts, they do not deal very well with a host of disease causing viruses, some spores/cysts, emerging contaminants such as industry based, personal care, and household products, as well as pharmaceuticals, surfactants and more. Microplastics have now arisen as a major concern leading the federal government to officially list them as a toxic substance. Let's explore these risks in a little more detail and then put forward solutions to deal with them.

VIRUSES

Viruses in wastewater pose a significant risk to human health (74,77). Consider the following. Conventional full scale wastewater treatment methods release infectious and non-infectious viruses in their effluent (49,54,55,59). Wastewater is one of the most concentrated sources of infectious viruses. In the US it has been reported that the mean concentration of enteric viruses in wastewater is 7000/litre and it has been reported as high as 10 to the 9th per litre (42,73).

There are at least 150 different viruses that appear in wastewater (77) and the volume of viruses in wastewater varies day to day, week to week and season to season. Many of these viruses have been identified as pathogens while many are unknown with respect to their disease causing capability. Common etiological agents are adenoviruses, enteroviruses, caliciviruses where norovirus is the most frequent infecting agent and rotavirus, a common cause of gastroenteritis in children.The lack of correlation between standard fecal contamination coliform indicator tests and pathogenic viruses has been an unresolved major public health dilemma for many decades (24).

Viruses from wastewater cause a variety of diseases including gastroenteritis, myocarditis, meningitis, hepatitis, conjunctivitis, and respiratory infections. There can be severe consequences for the immunocompromised. Since 1980 the CDC reports 70 outbreaks in the USA but there is significant underestimation due to poor reporting. World-wide 2-12 million people die per year from wastewater diseases. There have been many outbreaks where viruses have been suspected but current methods have not been sufficient to allow for identification (77).

Some viruses, particularly the non-enveloped (no phospholipid bilayer capsule) can be very difficult to kill. Resistance to UV light characterizes many viruses and it is hard to predict response. Adeno and Rotaviruses are particularly resistant to UV light (77). And viruses are capable of living for several days in a marine environment. Interactions between viruses and the environment are diverse and at times unpredictable and the fate of viral nucleic acids resulting from destruction/disinfection is unknown.

There are a number of literature reports describing some limitations on the effectiveness of UV light in destroying viruses prior to discharge as wastewater. While many factors can influence the effectiveness of UV light, one of which is turbidity, the volume of reports is a cause for concern. Recent studies (60,61) on the effect of UV light on viral load at two Calgary and one Edmonton wastewater plant are of particular interest. Dr.Judy Qiu and others in the study of two wastewater sites in Calgary compared viral load pre and post UV treatment at a dose of 30 mJ/cm2. Infectious viruses were present in 98% of pre UV samples and in 76% of post UV samples. The viruses present included Noro, Sapo, Astro, Rota, Reo, Adeno, Entero (coxsackie and echo) and human polyoma virus. **The authors concluded that the presence of infectious viruses in UV treated wastewater effluent discharged to the river suggests potential risk to human and environmental health as well as a need for monitoring the presence of virus in treated wastewater.**

It should be added that there is limited data on the UV disinfection effect on human enteric and other viruses during wastewater treatment. It is known that certain parameters affect the impact of UV disinfection including intensity, exposure time, dose, turbidity of effluent, and transmittance. Sensitivity to UV light also varies as a result of varying viral characteristics such as gene structure and DNA repair mechanisms (4,13).

The issue of monitoring for virus detection is also very challenging (26,35,42,74,75). Viruses are heterogeneous, samples are complex, and testing is technically demanding. There can be many genetic subtypes, new strains are emerging and mutations through adaptation add to these challenges. For example and more specifically the high genetic variability of norovirus makes detection a significant challenge. And coliform counts are a poor surrogate for assessment of viral load (24). Coliform counts can be within an acceptable range while at the same time viral contamination levels can be very high. Presently monitoring systems are simply not designed for viral load.

An important issue is the survival time for viruses and other indicator organisms in discharged effluent. There is very little data on this and many factors affect the persistence of these organisms such as temperature, light, nutrients, salinity and genetics (48,54,74,77). It can be as long as 14 days for a 1 log reduction in enteroviruses, 58 days for adenoviruses, up to 4 days for noroviruses (48). But there are significant data gaps for enteroviruses, hepatitis A, noroviruses and rotaviruses. **One should be cautious about any assumptions of short survival times for these pathogens in discharged wastewater.**

Adding to the uncertainty, it has been reported (20) that both viruses and bacteria can bind to sediments on the ocean floor and be protected from destruction by usual natural forces thereby promoting their continued viability and in a non-culturable state. Release of these bound particles into the water can occur during turbulence or other conditions favourable for release. There is need for more research in this area, but this phenomenon raises questions about risk and the reliability of standard methods of monitoring and detection for the presence of these pathogens.

NOROVIRUS

Norovirus is an agent of particular concern in these waters. More detail about the specific risks posed by this virus in a wastewater discharge and /shellfish cultivation environment would be in order.

Norovirus infections are ubiquitous. The Center for Disease Control and Prevention reports that one out of every five cases of gastroenteritis is due to this virus world-wide. It is the most common cause of gastroenteritis with 685 million cases annually, 200 million of which are in children. There are 50,000 child deaths annually second only to those caused by the Rotavirus (74,77).

The virus is spread by the fecal/oral route and of course finds its way into sewage. Questions have been raised about the effectiveness of UV light in its destruction (32,60). It is transmitted as a zoonotic disease because it finds its way into shellfish, particularly oysters which concentrate the virus by filter feeding like other shellfish and which become a reservoir for the virus. Infections occur when they are consumed raw or undercooked (24,74).

Many outbreaks of gastroenteritis due to Norovirus have occurred throughout the lower mainland of BC and other parts of the world where oysters from this region are shipped and consumed. **The BC Centre for Disease Control (BCCDC) reported on hundreds of cases during a 5 month period from Nov. 2016 to March 2017, where more than 400 people from across Canada developed Norovirus infections in association with the consumption of B.C. oysters leading to the closure of 13 oyster farms (40)**. The presence of Norovirus was detected in oysters from these shellfish farms. There have been other closures of oyster farms in the Vancouver Island as well as other areas of the Salish Sea on several occasions (73). The source of the contamination has not been precisely determined but it could be sewage from fishing boats, pleasure craft, leaking septic fields or wastewater discharge from many land based sewage systems that are located in proximity to Baynes Sound.

There have been similar experiences in other parts of the world. In England for example and in response to outbreaks, Norovirus was found to be present in all of the wastewater resulting from multiple types of treatment systems (24). While there was some degree of removal with some systems, membrane bioreactors performed the best, although not with complete removal.

Their conclusion is that viruses in shellfish, particularly oysters, present a public health concern and the European Food Safety Authority has recently produced an opinion paper which concludes that production of bivalve molluscs in the vicinity of human pollution is a high risk practice for viral contamination (66). They also conclude that zones for shellfish harvesting in the vicinity of sewage discharge points should be prohibited (21,18). There are some other aspects of Norovirus biology that reinforce this conclusion.

A very low dose of Norovirus is required to cause infection. This is important particularly since some have emphasized the short survival time of Norovirus in ocean water. Survival time can be as long as several days, sufficient time to allow for contamination of shellfish farms in close proximity (48). It is also important because there is no test currently available that assures Norovirus is sufficiently killed and there is a poor understanding of Norovirus inactivation (23). And the concentration of Norovirus in oysters has been correlated with the concentration in wastewater effluent (21).

The infectious dose of Norovirus can be as few as low as 18 viral particles(40). Compare this to the thousands of particles often required to cause infections of other types. It should also be noted that norovirus bioaccumulates in shellfish particularly oysters (24). Low numbers of virus in wastewater would still be a concern when amplification of concentration occurs in shellfish. New Zealand authorities have raised another concern. High levels of cadmium in their oceans has raised the possible risk of toxic organ damage as well as immunosuppression (15). Cadmium accumulates in shellfish such as oysters. Norovirus accumulates in oysters leading to a potentially deadly combination. As reported by Bendell (SFU) and others cadmium levels are particularly high in certain parts of Georgia Strait (7). Is this an added risk associated with the consumption of shellfish from areas bathed by incompletely treated wastewater?

There are other complexities associated with controlling Norovirus infections. There is considerable genetic diversity with many subtypes (26). The virus undergoes rapid evolution with new strains appearing every 2-4 years, there is a low infectious dose and there is resistance to disinfection. Added to this is the challenge and complexity of conducting useful surveillance and assessing risk (35). As previously stated bacterial indicators are not useful in assessing the risk from viral pathogens such as norovirus (24). And there are significant uncertainties about the length of ocean survival (24,48). The European Food Safety Authority Biohazards Panel also concludes that there is no threshold infectivity limit for NoV detected by PCR (polymerase chain reaction) (66). The dose required for infection depends on genetic characteristics. They go on to say "**the most effective public health measure to control human NoV infection from oyster consumption is to produce oysters from areas which are not faecally contaminated particularly given ineffectiveness of current depuration and relaying procedures".**

Shellfish harvesting areas and wastewater treatment plant effluents are a very bad combination!!

BACTERIA AND PARASITES

In general wastewater treatment systems such as the SBR plus the UV light proposed for Bowser are effective in removing/killing pathogenic bacteria and some viruses but not so for many spores, cysts and parasites. However, not unlike viruses, for bacteria there is a range of doses of UV light required for inactivation depending on the particular bacteria and even the particular genotype within strains of a particular bacterial species. In addition there has been increasing concern about the implications of bacterial DNA repair mechanisms for reactivation and the increasing evidence for enhanced antibiotic resistance enabled by wastewater treatment systems. With global warming there is also increasing concern about health risks associated with various types of Vibrio, the presence of which also does not correlate with coliform counts.

Much greater doses of UV light are required for viruses, spores, cysts and certain parasites. For example viruses in general require 3-4 times the dose, spores 9 times and some cysts 15 times (13). Also the extreme resistance of Giardia Lamblia cysts make it unlikely that any normal dose of UV light would be sufficient to destroy them. It has been reported that Giardia cysts need 68 times the usual dose (37).

The range of responses for various bacteria are reasonably comparable and hence E. Coli or coliform counts are useful as a quantitative measure for disinfection (13). But these measures cannot be used for viruses, spores or cysts. This is important because, as an example, cryptosporidium and giardia cysts which spread by the fecal/oral route have been found in a high percentage of effluents arising from conventional wastewater treatment plants and where coliform counts were within an acceptable range (11). Also as has been previously stated coliform counts have been shown to be a poor surrogate measure for assessing the presence of worrisome levels of virus.

Giardia is a leading cause of gastroenteritis and there have been many community outbreaks worldwide. Generally, for every case reported there are 14 in the community (UK). Asymptomatic carriage is common. Activated sludge and UV treatment are not effective in their removal. Active oxidation, not part of the Bowser proposal, has been found to be effective. And transmission can occur when seawater is in contact with the mouth. It is also present in sludge derived from wastewater treatment which is used for agricultural purposes and from which it pollutes shallow water becoming part of the transmission cycle. And Giardia, along with enteric viruses and Vibrio for that matter, are considered as beach bathing risks. Cryptosporidium have also been found in wastewater. They are not removed by activated sludge treatment but, except for the oocysts, they are sensitive to UV light. Oocysts are highly resistant requiring a high dose of UV light, in the range of 230 mJ/cm2 to kill. It is clear that a multi barrier approach is necessary for cryptosporidium, however stabilization ponds and constructed wetlands are efficient in their removal.

As mentioned earlier resistance to UV light by E. Coli varies significantly. It is also interesting that UV inactivated E. Coli are able to repair within two hours and that some naturally occurring heterotrophic bacteria treated with 140 mJ/cm2 (a higher dose than proposed for Bowser) were able to regrow (4). So questions have been raised about the extent to which bacteria can undergo photoreactivation when exposed to natural light following UV treatment. It has also become clear that different species of bacteria display different responses to UV light and different DNA repair potential. A higher dose along with a low nutrient level helps to stop photoreactivation as does delaying exposure to natural light. The higher the UV dose the less opportunity for different species to undergo DNA repair and reactivation. Post UV repair has important implications for a shellfish industry in close proximity. However more research on DNA repair mechanisms that enable compensation for UV light damage is needed.

Questions have also been raised about the extent to which wastewater treatment systems contribute to the development and enhancement of antibiotic resistance. **It has been shown**

that bacteria not killed during treatment have a higher proportion of resistant organisms, reportedly as high as 10 times more resistant. As published in Scientific American there is concern as to whether we are promoting 'superbugs' with antibiotic resistant genes spreading like 'Darwinian wildfire' (38). As resistant bacteria enter wastewater treatment plants the conditions suitable for good bacteria to break down organic matter, particularly within sludge, are such that resistant bacteria also reproduce quickly and they share DNA, transferring resistance to other organisms. This raises the possibility that resistant organisms gain access to soil through agricultural use of sludge. Antibiotic resistant gene transfer has also been reported to occur when bacteria enter the ocean through adherence to microplastics and thereby gaining access to filter feeding shellfish. Antibiotic resistant Pseudomonas aeruginosa has been found downstream from wastewater treatment plants that receive discharges from hospitals (39). They have also been found in the resulting sludge through which they may contribute to community acquired infections when it is used for agricultural purposes. The use of reverse osmosis or activated carbon could address this issue (33). Evolution will always outsmart our ability to design more intelligent drugs.

Various strains of Vibrio are naturally occurring disease producing organisms found increasingly in coastal areas of warming oceans worldwide (5,10,27). Vibrio vulnificus, parahaemolyticus and fluvialis can concentrate in oyster tissue and other shellfish causing gastroenteritis when consumed uncooked (30). According to Daniel's and also reported by the CDC infections from vulnificus are the leading cause of seafood deaths in the USA (16). It can also cause septicemia with a 50% mortality and necrotizing fasciitis if it enters through a break in the skin. Vibrio parahaemolyticus can also cause gastroenteritis as it did in a recent outbreak caused by contaminated herring roe in the Bowser area as reported by the First Nations Health Authority and Island Health in May 2018 . It can also be found in oysters and mussels.

While these organisms are naturally occurring in the environment, infected individuals excrete organisms through their faeces hence causing them to enter the wastewater treatment system (46). What happens to Vibrio in wastewater treatment plants has not received a lot of attention. Hopefully the increasing number of outbreaks will lead to more study. It is an adaptable organism and new strains are emerging. It has been assumed that conventional wastewater treatment can control it. This is not true. Although more study is needed, they have been isolated from wastewater effluent in both Spain and South Africa in multiple wastewater treatment systems (10,50). Although Vibrio organisms are not removed by activated sludge treatment they are quite sensitive to UV light. The various species of Vibrio, however, have differences in their genetic makeup which leads to different levels of sensitivity to UV light. At the same time, they seem to have strong survival strategies adhering well to different substrata. Some have also assumed that their behaviour in wastewater is the same as E. Coli. The presence of Vibrio within wastewater does not correlate well with coliform counts. Specific monitoring for Vibrio pathogens in treated effluent can contribute to the control of risk and enhance understanding of how these organisms evolve and behave.

The dosage of UV light should be at a level equal to the highest required for the removal of the most resistant.

MICROPLASTICS

There is widespread contamination of the Georgia Strait/Salish Sea region with microplastics. This is in three forms, micropellets, microfibres and microfilaments (34). The volume of microplastics according to a study published by SFU researchers is equal to or greater than the amount of organic matter and silt in the sea bed (34). This is a worldwide issue which has reached crisis proportions with the killing of sea life, adverse effects on coral reefs, the creation of dead zones where nothing can live and threats to human health as they enter the food chain (43).

It is estimated that 19 billion pounds of plastic enters the oceans worldwide every year and that this will double by 2025 (29). It has been estimated that there are 9200 microplastic particles per cubic meter of Salish Sea seawater (18).

There are many well known sources of plastic contamination of our oceans. What is not commonly understood by the citizenry is the extent to which personal products and clothes washing activities contribute to this issue. Microplastics, particularly micropellets/microbeads contained in facial scrubs, toothpaste, hand sanitizers, other personal care products and clothing find their way into the wastewater treatment system that cannot filter such fine particles. One average synthetic jacket releases 1.7 grams of microfibres per load. Wastewater treatment plants are acting as a route for microplastics to gain access to the aquatic environment. Clearly this is having an impact on the environment and their is concern about risks to human health (44).

What we consume from ocean sources is significantly contaminated with microplastics. This is widespread up the food chain starting for example with lower levels such as zooplankton and including those items used as food sources by humans such as oysters, mussels, clams and fish. More than a quarter of all fish world wide contain microplastics. The United Nations says microplastics are a growing concern for human health (44).

The source of microplastics in consumed seafood requires further study. There clearly are multiple sources from which microplastics enter the oceans. The shellfish industry itself through the use of many plastic materials contributes to this issue. Dealing with microplastics requires aggressive broad based action and each jurisdiction must do its part. For Bowser to do its part, a conventional wastewater treatment system using SBR does not qualify.

Teasing out the effect of microplastics on human health will be challenging because of many confounding variables. It is clear however that microplastics are entering our bodies as well as other members of the animal kingdom. Research carried out in mice show the accumulation of microplastics in the liver, kidney and gut (17). Their presence induces disturbances in energy and lipid metabolism as well as oxidative stress and biomarker responses suggest neurotoxicity. The biological and biochemical similarities between mice and humans would strongly suggest similar impacts on humans.

Microplastics have a damaging effect on shellfish (63). Some filter feeding species of sea life, particularly shellfish are showing a tendency to inadvertently consume microplastics preferentially as a food source rather than phytoplankton. And the adverse effects are clear. Oysters that contain microplastics are less robust, are smaller and their ability to reproduce is halved. They are consuming a cocktail of substances harmful to their health and survival. It is clear that microplastics are having an adverse impact on sea life. Along with what has been found in mice there may be a signal of what is in store for humans. Are these the canaries in the coal mine for humans? Consider the following.

Of major concern is the possible role that microplastics play as vectors for chemicals and bacteria that adhere to them (52,53,67). There is abundant colonization of microplastics in wastewater treatment plants by certain bacteria commonly associated with antibiotic resistance suggesting that microplastics could serve to facilitate horizontal gene transfer. In addition microplastics serve as a focal point for bacterial assemblages. For example various strains of Vibrio have been known to 'hitchhike' a ride on microplastic particles. This includes strains such as parahaemolyticus, vulnificus and cholera. These are pathogenic for humans. As global warming continues and encourages further growth of these organisms, microplastics as vectors may become a more significant problem. And this is just Vibrio. It could be the tip of the iceberg particularly with the high bioconcentration factors associated with filter feeders in contaminated waters.

Microplastics act as magnets for a variety of pollutants and additives. Contaminants enter shellfish and other sea life by adhering to microplastics at levels that compromise key functions. Lugworms for example have been studied in relation to the adverse effects of pollutants such as nonylphenol transmitted through adherence to microplastics (9). The result was an increase in oxidative stress and an increase in mortality rate by 55%. Similar adverse effects have been noted in shellfish. In short, microplastics serve as a vehicle for the transmission of persistent organic pollutants (PCBs, polyethylene terephthalate, pesticides and more) which get biomagnified as they move up the food chain and which among other things are adverse to reproductive health.

Although it is only part of the problem, various approaches are under consideration towards the removal of microplastics from wastewater (70). And of course preventing these substances from entering the wastewater system in the first place should be part of the goal (45).The Danish have introduced a new membrane technology (VeSave) which filters out microplastics. Electrocoagulation has also been put forward as a solution. Membrane bioreactors are known to remove 99.9% of microplastics. Clearly more must and can be done. Rather than relying on the limits that can be achieved by conventional wastewater treatment systems, such as what is proposed for Bowser, we should aim for a more progressive and effective solution.

EMERGING CONTAMINANTS

Emerging contaminants are chemicals, some of them new, which have not been subject to any specific form of regulation and whose impact on the environment and human health is not well understood. It includes pharmaceutical residuals, illicit drugs, household products, cosmetics, metals, endocrine disrupting compounds, disinfectants, surfactants, plasticizers, manufactured nanomaterials (sunscreens, health care products), fire fighting foams, lubricants, and detergents (containing PFC, PFOS, PFOA) (76).

Based on recent studies emerging contaminants are suspected of being teratogenic, mutagenic and carcinogenic to both humans and animals (36,76). They appear to have meaningful connections to cancer, reproductive risks, disruptions to the endocrine system, interference with neurotransmission in marine organisms as are potentially lethal. Endocrine disruption can lead to altered hormone regulation which can lead to tumours, birth defects and developmental disorders. Intersex characteristics in fish is one notable example (59,76). Although adverse effects arising from animal experiments cannot be ignored, there is no large scale evidence that proves an association between emerging contaminants and adverse health effects for humans (36). This, despite the fact that many of these compounds have been found in human tissues. And determining adverse effects will be challenging in the face of many confounding variables.

It is important to know, however, that there is a rapidly increasing use of many of these products and the hazards of existing, let alone new ones, have not been documented. It is important to emphasize that all of these products have been detected in varying levels in wastewater. They are also known to attach to plastics which are consumed by fish and other marine life thereby contaminating them with emerging contaminants (53). And there are no regulations specific to these contaminants. A National Wastewater Report calls for a renewed focus on emerging contaminants and has called Canada ‘laggard’ in this regard (47). There is also a lack of good analytical approaches to assessing the content of wastewater for emerging contaminants resulting in underreporting of the extent to which these contaminants are entering wastewater and eventually our oceans. And sludge which can act as a concentrator is applied to agricultural land without analysis (59).

Various assessments have been carried out on a range of wastewater treatment systems regarding their capability in removing these contaminants. Their effectiveness in removal varies widely, even varying for the same system tested at different times, no doubt partly due to the differing molecular characteristics of these compounds. An International US/Canada/Great Lakes Commission, as published in Scientific American, concluded that only about one half of drugs and emerging contaminants were removed by conventional sewage treatment (8).

Conventional wastewater treatment plants are not designed to deal with these contaminants (76). This includes what has been proposed for Bowser. So what would work? What technologies are available that could effectively remove these contaminants? Some of the most promising developments are reverse osmosis where effluent is forced through an extremely fine membrane to remove dissolved material (62,76). It is primarily used in water reclamation systems. Another is nanofiltration, which is relatively new, and where the pores are 1nm. It may be preferable to reverse osmosis because of lower energy costs.

It is recognized that more research is needed to understand more fully the risk of these compounds to health and the environment. In the meantime, wastewater should be treated to the extent that it meets certain water quality standards to prevent risk to health and the environment and that standards should be zero for emerging contaminants. Technology should be selected to meet this end (33,72).

Wastewater systems should not be designed in a manner where one size fits all. They should be strategically designed in relation to the specific contaminant risks to be mitigated and should be adapted as new risks are identified.

THE SALISH SEA ENVIRONMENT.

When asked how we are managing our aquatic resources, Leah Bendell, Professor of Marine Ecology and Ecotoxicology at SFU and a leading researcher on microplastics and other contaminants in the Salish Sea, simply said that 'the situation is grim and getting grimmer and the consequences will be significant'. Many years ago when Jacques Cousteau toured these waters he was clear that this sea is in decline. Further decline was reaffirmed by his granddaughter Alexandra during a visit to these waters within the past two years when she pushed for conservation of this area. Inevitably countless variables have contributed to the decline and consequent reduced productivity and harvesting of biological resources in this area. The influence of climate change, water warming, pH and salinity changes need attention but are not within our immediate local control. We certainly do not wish to aggravate this grim situation through the types of decisions we make about wastewater treatment systems.

But let's reflect for a moment on some of the impacts of these various changes and in doing so recognize what Bendell said; that the issues with shellfish may well be our canaries in the ocean (16). They could be signals for what might happen with further degradation to other sea life but also for humans. What is happening to farmed shellfish for example will soon be experienced by the wild and it will expand from there (20).

Over decades there have been indications of degradation of the Salish Sea environment and a distinct lack of integrated management from all levels of government. The loss of kelp over most of Georgia Strait has meant a loss of habitat for forage fish such as herring—a necessary link to predators up the food chain such as salmon, eagles, sea lions and whales. There has been an increased incidence of toxic algae blooms resulting from eutrophication driven by excessive oxygen demanding substances and warming of the oceans (25). Other events have included the collapse of the coho fishery in the Georgia Strait which was evident in the 1980s, the uptake of organic contaminants in fish migrating through the Fraser River estuary, the discharge of specific chemicals at concentrations lethal to aquatic organisms and the recognition of the toxic effects of mercury and dioxins leading to the closure of fisheries to name a few. **And just recently a Seattle toxicologist with the National Oceanic and Atmospheric Administration (NOAA) reported biopharmaceuticals in high levels (amphetamines and antidepressants) in estuary waters and the tissues of smolts and Chinook salmon. This has lead to altered fish behaviour, reproductive difficulties and a 45% lower survival rate. 81 different chemicals were found in the effluent and 42 were at elevated levels in the fish (64). Chinook are a food source for Orca whales which are in decline.**

It is important to remember that fish do not recognize human defined boundaries for effluent discharges. It has been documented that fish do not always avoid potentially lethal or debilitating circumstances. In short fish cannot readily adapt to human driven changes and will use degraded habitats even those potentially lethal. And it is telling that fish have responded to contaminants so dilute as to be beyond analytical detection. And monitoring of receiving waters is likely to be inconclusive in view of much dilution, compounded by the inadequacy of predischarge information.

Adding waste to water will change that water. Regardless of our ability to measure the impact of doing this, there will be unforeseen consequences due to unpredictable variables and their unknown interactions. The expansion of domestic sewage discharges and the myriad of associated contaminants which are not adequately monitored or understood has led in part to this large scale habitat degradation. Cause and effect relationships are inevitably multivariate and hence are unlikely to be accurately identified or characterized. We need both a common sense and very cautious approach to aquatic management for the protection of ecosystems. A refusal to discharge effluent directly into Baynes Sound with all the attendant risks is a good first step for this area.

WHAT SHOULD HAPPEN IN BOWSER?

There is an opportunity to develop a wastewater treatment system for Bowser that deals more effectively with various risks including viruses, emerging contaminants, microplastics and differing elimination/disinfection requirements for some bacteria, spores and parasites. Monitoring systems need to be designed to regularly assess how these and other traditionally measured risks are being managed. We must move beyond conventional approaches that were not designed to deal with a broader range of risks and move in concert with global thinking. We have an opportunity to do so. Bowser is not limited by having to retrofit an old system. This is an entirely new installation of a wastewater treatment system for the community of Bowser.

Notwithstanding the real risks for the shellfish industry and public safety, it is acknowledged that if the current plan for Bowser proceeds, it will likely have a small and difficult to measure yet cumulative impact on Baynes Sound and the more expanded environment of the Salish Sea.

This is because there are a number of much larger and more impactful wastewater treatment systems emptying into the same bodies of water, including BCs major cities and more locally Nanaimo, Parksville /Qualicum, and Comox/Courtenay. And there are sources of raw sewage emanating from fishing boats, pleasure craft, possibly septic fields and raw sewage discharged as treatment plants are bypassed during rainstorms such as what happens at Iona Island which serves Vancouver. All of these need addressing. But we must start somewhere.

It is disconcerting that many different approaches to treating wastewater throughout the Salish Sea area are in existence. We are all discharging into the same body of water and yet decision making processes are not coordinated to achieve a standardized quality of effluent. The Duke Point wastewater system is different from French Creek which in turn is different from what is proposed for Bowser, which in turn is different for what is proposed for Union Bay. And Sechelt has established a gold accreditation award winning wastewater resource centre based on progressive European systems facilitating reuse of reclaimed water. So Bowser, although whatever it does is likely to have a small impact, is starting from scratch and has the opportunity to do it right and hopefully stimulate others to follow suit. New wastewater systems should not threaten ecosystem integrity in relatively clean shellfish waters and these waters should not be compromised through new developments by the deployment of outdated wastewater technology. And such progressive systems are available (1,33,57,58,62,63,70)

It is hoped that eventually a coordinated, consistent Salish Sea wastewater treatment system can be achieved through some integrated governing body with the quality of effluent and the health of the Salish Sea as its core mission. It would also be helpful if there could be a consistent and publicly reported system of performance indicators based upon a standardized and comprehensive monitoring system.

As previously described, the system proposed for Bowser in 2017 by Stantec Consulting and agreed to by the Regional District of Nanaimo (RDN) includes a Sequence Batch Reactor (SBR) plus 60-90mj/cm2 of UV light with discharge into Baynes Sound not far from a scallop farm and in close proximity to many oyster farms (69). The report sets aside the option of a Membrane Bioreactor (MBR) as well as a land based option with limited analysis. The report also did not specify how difficult to kill viruses, spores and cysts or emerging contaminants/microplastics would be dealt with. The installation of this system would not deal adequately with many contaminants and infectious agents which would be of concern for the environment, the health of sea life and human health.

A number of criteria were considered by the consultants in making this recommendation but quality of effluent was not among them. In addition a prior report entitled the Chatwin Study (2011) put forward a land based option with future expansion potential to serve 4000 people that was not subjected to a full and objective analysis by Stantec Consulting (14). While Stantec did consider 4 ground based options, not included were other legitimate opportunities identified by the Chatwin feasibility study. That study included two suitable sites with good potential and deep soils allowing for community forests and trails and with similar operating costs. It is true that future land acquisition costs could be a concern for expansion of a land based system but this concern was dealt with very lightly.

Dr. Nicholas Ashbolt points out that there is a growing consensus amongst global experts that calls for a shift from conventional centralized water services to alternative decentralized strategies based on the circular economy with more reuse and containing emerging contaminants (1,68). The Dutch have pursued a wetland model based on this global consensus.The Alberta Recovery Centre also exemplifies such a model, a model that may be eminently suitable for Bowser.

For Bowser specifically we believe that the wastewater treatment process selection should be guided by the following characteristics:

- that the selection of the treatment process should be strategic and in relation to the contingencies to be faced.
- quality of the effluent should drive how the wastewater treatment system is engineered
- there should be comprehensive risk based monitoring for the full range of infectious organisms, emerging contaminants and microplastics in wastewater that are publicly reported
- consistent standards for the quality of effluent being discharged by multiple wastewater treatment facilities into the Salish Sea should be established
- that a new installation for a community such as Bowser should be based on global consensus thinking with a view to addressing the current and preparing for contingencies that will inevitably arise in the future.

The main goal of the community of Bowser is to stop sewage from being discharged into the ocean. Consistent with this we would ask Federal and Provincial Authorities to support this goal by endorsing a land based system with constructed wetlands and with water reuse consistent with current global thinking as previously described. In addition we respectfully request that an integrated evidence driven governance and policy setting mechanism be established to oversee decisions in the interests of assuring safety and conservation of the Salish Sea and Baynes Sound.

If a land based option is not to be and discharge into the ocean is to occur, then the proposed system should be modified by following a multistep process to include microfiltration (possibly MBR), with double the proposed dose of UV light to the 100-200 mJ/cm2 range, adjunctive peracetic acid at 5 ppm (as used in the Northwest Langley system) for difficult to kill spores, viruses and cysts, granular activated carbon to remove various chemical contaminants and tertiary treatment to remove remaining inorganic compounds and substances such as nitrogen and phosphorous (29,53,54,). Only then would the effluent be close to suitable for discharge into the ocean in proximity to sensitive shellfish harvesting areas and for contributing to the protection of the health of sea life and humans.

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Ian Birtwell has a BSc (Hons.) in Botany and Zoology, University of London, UK. and a PhD from Kings College, University of London. He has undertaken scientific research on the effects of and the management and regulation of, contaminants, municipal and industrial effluents discharged into the aquatic environment. His employment history spans more than 40 years in Canada during which time he has conducted and directed research on the effects of contaminants, effluents, and natural factors on aquatic organisms, managed DFO's Pacific Regions Water Quality Unit, and the Habitat Research and Pollution and Toxicology programs. His applied research findings have contributed to the protection and management of aquatic organisms at the regional and national level. Dr. Birtwell is an acknowledged specialist on the effects of deleterious substances on fish and their habitat. He has been a spokesman for DFO and had considerable involvement as an expert witness on behalf of DFO, Environment and Climate Change Canada, and in private prosecutions concerning violations of the federal Fisheries Act, and protection of aquatic organisms. He has received the Fisheries and Oceans Deputy Minister's Commendation and the Governor of Canada conferred upon him the Commemorative medal for the 125th anniversary of the Confederation of Canada for significant contributions to Canada. Dr. Birtwell continues to work in an advisory capacity.

Thomas Gates has a BSc. in Zoology with Marine Science Studies and an MSc in Aquatic Eco-Physiology. He conducted research in the latter as a research associate at the U of C Aquatic Ecology Program. He also served for Saskatchewan Environment as a water quality specialist/Environment Officer, a mines pollution control inspector, and as a Forestry Management Plan/Environmental Assessment Supervisor. He also served as a Senior Environmental Health and Safety Inspector for the Canadian Nuclear Safety Commission. Thomas established the Saskatchewan Uranium Mines Cumulative Effects Monitoring Program and Forestry International Standards Association ISO 14001 Environmental Management System. He is the recipient of the Premier of Saskatchewan Award for Excellence in Public Service. Thomas was a member of the Alberta Society of Professional Biologists from 1974 to 2015.

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REFERENCES

1.Alberta Resource Recovery Centre, ARRC Project Brief, (Oct 27, 2017).pdf

2. Ashbolt, N.,Riedy, C., and Haar, C., Microbial Health at Sydney's Coastal Bathing Beaches, Proceedings of 17th Federal Convention of AWWA, 16-21, March, 1997, Melbourne, V.2, pp:104-111.

3. Barasel, C., Westling, K., Samuelson, O., Anderson, S., Royen, H., et al. Membrane Bioreactors Processes to Meet Today's and Future Municipal Sewage Treatment Requirements, International Journal of Water and Wastewater Treatment, April 28, 2017, V. 3.2.

4. Baron, J., Repair of Wastewater Microorganisms after UV Disinfection under Semi-natural Conditions, Water Environmental Research, V.69, July/August 1997, pp.992-998.

5. BC Centre for Disease Control and the National Vibrio Working Group, Recommendations from the National Working Group for Vibrio parahaemolyticus Control in BC Oysters for Raw Consumption, Aug. 24, 2016

6. Bendell, L., Canaries of the Sea: Are Microplastics the Final Challenge to Shellfish? Department of Biological Sciences, Simon Fraser University. Abstract by email.

7. Bendell, L., Chan, K., St. Clair, T., and Walling, H., Proceedings of the Workshop; Cadmium in Shellfish from the Pacific Northwest: Status and Health Concerns, 2010

8. Bierkowski, B., Only Half of Drugs Removed by Sewage Treatment, Scientific American, Nov. 22, 2013.

9. Browne, M., Niven, S., Galloway, T., Rowland, S., Thompson, R., Microplastic Moves Pollutants and Additives to Worms Reducing Functions Linked to Health and Biodiversity, Current Biology, 2013; 23(23), pp. 2388-92, DOI 10:1016/j cub 2013.16.012.

10. Canigral, I., Moreno Y., Alonso, J., Gonzalez, A., and Ferris, A. Detection of Vibrio vulnificus in Seafood, Seawater, and Wastewater Samples from a Mediterranean Coastal Area, Microbiological Research, V. 165, Issue 8, Oct. 2010, pp. 657-664.

11. Castro-Hermida, J., Garcia-Presedo, I., Gonzalez-Warleta, M., Mozo, M., Cryptosporidium and Giardia Detection in Water Bodies of Galicia, Spain, Water Research, 2010; 44(20): 5887.

12. Center for Disease Control and Prevention: Norovirus Worldwide: Global Trends, 2018.

13. Chang, J., et al, UV Inactivation of Pathogenic and Indicator Microorganisms, Applied Environmental Microbiology, June, 1985, pp. 1361-1365.

14. Chatwin Engineering, Feasibility Study for Area H Bowser Bowser Community Sewer Servicing Study, March 2011.

15. Conn, A., The Importance of Norovirus and Cadmium in Shellfish and Implications to Human Health, Masters of Science Thesis, University of Canterbury, 2010.

16. Daniels, N., Vibrio vulnificus Oysters: Pearls and Perils, Clinical Infectious Diseases, V.52, Issue 6, March 2011, pp.788-792.

17. Deng, Y., Zhang, Y., Lemos, B., Ren, H., Tissue Accumulation of Microplastics in Mice and Biomarker Responses Suggests Widespread Health Risk Exposure, Scientific Reports, 7, Article no: 46687 (2007).

18. Desforges, J., Galbraith, M., Dangerfield, N., Ross, P., Widespread Distribution of Microplastics in Subsurface Seawater in the Northeast Pacific Ocean, 2014, Feb. 15:79(1-2), pp 94-99.

19. Dutta, A., Sarkar, S., Sequencing Batch Reactor for Wastewater Treatment: Recent Advances, Current Pollution Reports, Sept. 2015, V. 1, Issue 3, pp. 177-190.

20. Ecological Importance of Baynes Sound and the Aquaculture Industry, Adimsblog.wordpress.com.

21. Flannery, J., Keaveney, S., Rojko-Nenon, P., O'Flaherty, V., Dore, W., Concentration of Norovirus during Wastewater Treatment and its Impact on Oyster Contamination, Applied and Environmental Microbiology, posted on-lime, 2012.

22. Green Alternatives to Bowser Village Centre Marine Effluent Disposal, www.sosbowser.ca, Nov. 23, 2017.

23. Hassard, F., Groyther, C., Farcas, K., Andrews, A., jOnes, V., Cox, B., Brett, H., Jones, D., McDonald, J., and Malham, S. Abundance and Distribution of Enteric Bacteria and Viruses in Coastal and Estuarine Sediments—A Review, Frontiers in Microbiology, Nov. 1, 2016: 7; 1692.

24. Hassard, F., Sharp, J., Malham, S., Critical Review on the Public Health Impact of Norovirus Contamination in Shellfish and the Environment: A UK Perspective, Food and Environment Virology, 2017; 9(2), pp. 123-141.

25. Heisler, J., et al, Eutrophication and Harmful Algae Blooms: A Scientific Consensus, Elselvier, V.8, issue 1, Dec. 2008, pp. 3-13.

26. High Genetic Variability of Norovirus Leads to Diagnostic Test Challenges, www.researchgate.net.

27. Horseman, M., Surani, S., A Comprehensive Review of Vibrio vulnificus: An Important Cause of Severe Sepsis and Skin and Soft Tissue Infection, International Journal of Infectious Diseases, V.15 Issue 3, 2011, pp. 157-166.

28. Igbinosa, E., Okoh, A., Antibiotic Susceptibility Profiles of Some Vibrio Strains Isolated from Wastewater in a Rural Community of the Eastern Cape Province of South Africa, BMC Microbiology, 2010, 10:143.

29. Jambeck, J., Geyer, R., Wilcox, C., et al, Plastic Waste Inputs from Land into the Ocean, Science, Feb. 2015, V. 347, Issue 6223, pp. 768-771.

30. Jones, J., Ludeke, C., Hastback, W., Abundance of Vibrio cholera, Vibrio vulnificus, and Vibrio parahaemolyticus in Oysters and Clams from Long Island Sound, Applied and Environmental Microbiology, Dec. 2014, 80(24), pp. 7667-7672.

31. Jumat, M., Hasan, N., Subramanian, P., Heberling, C., Colwell, R., Hong, P., Membrane Bioreactor-Based Wastewater Plant in Saudi Arabia: Reduction in Viral Diversity Load and Infectious Capacity. Water, 2017.

32. Kato, T., Degradation of Norovirus in Sewage Treatment Water by Photoanalytic Ultraviolet Disinfection, Nippon Steel Technical Report, 2005, no. 92.

33. Katsigrannis, A., et al, Removing Emerging Pollutants Through Granular Activated Carbon, Chemical Engineering Journal, V. 280, Nov. 15, 2015, pp.49-57.

34. Kazmiruk, T., Kazmiruk, V., and Bendell, L., Abundance and Distribution of Microplastics Within Surface Sediments of a Key Shellfish Growing Region of Canada, Ecotoxicology Research Group, Department of Biological Sciences, Simon Fraser University. Abstract by email.

35. Le Guyader, F., Detection and Quantification of Noroviruses in Shellfish, Applied and Environmental Microbiology, Feb. 2009, V. 75, no. 3, pp. 618-624.

36. Lei, M., Zhang, L., Lei, J., Li, J., Wu, Z., and Wang, Z. Overview of Emerging Contaminants and Associated Human Health Effects, Biomedical Research a International V. 2105, Article 10404796.

37. Li, D., Crack, S., Smith, D., Belosevic, M., Survival of Giardia Lamblia Trophozoites after Exposure to UV Light, FEMS Microbiology Letters, V.278, Issue 1, Jan. 2008, pp. 56-61.

38. McGlashen, A., Sewage Plants May Be Creating “Super” Bacteria, Scientific American, April 16, 2009.

39. Magalhaes, M., et al, Multidrug Resistant Pseudomonas Aeruginosa Survey In A Stream Receiving Effluents From Infective Wastewater Hospital Plants, BMC Microbiology, 2016, 16:193.

40. McIntyre, L., Galanis, E., Prystajecky, N., and Kosatsky, T., BC Oysters and Norovirus: Hundreds of Cases in Months with an “R”, BCMJ, Vol 59, No. 6, July August 2017, pp. 326-327, BCCDC.

41. Meador, J., Yeh, A, Gallagher, E, Adverse Metabolic Effects in Fish Exposed to Contamination of Emerging Concern in the Field of Laboratory, Environmental Pollution, V. 236, May 2018, pp. 850-861.

42. Meals, D., Harcum, J., Dressing, S., Monitoring for Microbial Pathogens and Indicators, US Environmental Protection Agency, Sept. 2013.

43. Microplastics and Human Health- An Urgent Problem, The Lancet Planetary Health, Oct. 2017, V.1, Issue 7 p. e254.

44. Microplastics in the Sea a Growing Threat to Human Health, UN Warns, Independent.co.uk, May 21 2016.

45. Microplastics in Wastewater Treatment Plants—A Totally Preventable Source—Sixth International Marine Debris Conference, (6 Abstracts), March 12-16, 2018, SAN Diego.

46. Morris, J., Acheson, D., Cholera and Other Types of Vibriosis: A Story of Human Pandemics and Oysters on the Half Shell, Clinical Infectious Diseases, V. 37, Issue 2, July 15, 2003, pp. 272-280.

47. Murphy, C., Microplastic Comparison in Farmed and Wild Shellfish Near Vancouver Island and Potential Implications for Contaminant Transfer to Humans, Master of Science Thesis, Royal Roads University, Victoria, BC, 2018.

48. Murphy, H., Persistence of Pathogens in Sewage and other Water Types, Global Water Pathogen Project, Aug 14, 2018.

49. Naidoo, S., Olaniran, A., Treated Wastewater Effluent as a Source of Microbial Pollution of Surface Water Resources, Journal of Environmental Research and Public Health, 2014, 11(1), pp.240-270.

50. Nongogo, V., Okoh, A., Occurrence of Vibrio Pathotypes in the Final Effluents of Five Wastewater Treatment Plants in Amathole and Chris Hani District Municipalities in South Africa, International Journal of Environmental Research and Public Health, 2014, 11(8) pp. 7755-7766.

51. Nesseth, D., National Wastewater Report Calls for Renewed Focus on Emerging Contaminants, Environmental Science Engineering, May, 2018.

52. Oberbeckman, S., Kreikemeyer, B., Labenz, M., Environmental Factors Support the Formation of Specific Bacterial Assemblages on Microplastics, Frontiers in Microbiology, 2017; 8: 2709.

53. Ocean Plastics Soak up Pollutants, Chemical and Engineering News, Aug., 22, 2012.

54. Okoh, A., Sibanda, T., Gusha, S., Inadequately Treated Wastewater as a Source of Enteric Viruses in the Environment, International Journal of Environmental Research and Public Health, 2010, 7(6): 2620-2637.

55. Osuolate, O., Okoh, A., Human Enteric Bacteria and Viruses in Five Wastewater Treatment Plants in the Eastern Cape, South Africa, Journal of Infection and Public Health, V.10, issue 5, 2017, pp. 541-547.

56. Parasidis, T., Konstantinidis, T., Alexandropoulos, I., Environmental Monitoring of Enteric Viruses in Wastewater, Viral Mycol, 2013, 2:e106.

57. Pare, J., Peracetic Acid—A New Solution for Wastewater Disinfection, Watertech, 2015.

58. Park, E., Lee, C., Bisesi, M., Lee, J., Efficiency of Peracetic Acid in Inactivating Bacteria, Viruses, and Spores in Water Determined with ATP Bioluminescence, Quantitative PCR, and Culture Based Methods, Journal of Water Health, March, 2014, 12(1), pp 13-23.

59. Petrie, B., Borden, R., Kasprzyk-Hordem, B., A Review on Emerging Contaminants in Wastewater and the Environment: Current Knowledge, Understudied Areas and Recommendations for Future Monitoring, Water Research, V. 72 April 2015, pp. 3-27.

60. Qiu, Y., Li, Q., Lee, B., Pang, X., Assessing Virus Reduction/Inactivation by UV During Municipal Wastewater Treatment, City of Calgary, 2018 Enviro Tech Presentation.

61. Qiu, Y., Neumann, N., Lee, B., Pang, X., Assessment of Human Virus Removal During Municipal Wastewater Treatment in Edmonton, Canada, Journal of Applied Microbiology, 119(6), Oct. 2015.

62. Rojosulochona, P., Preethy, V., Comparison on Efficiency of Various Techniques in Treatment of Waste and Sewage Water—A Comprehensive Review, Resource Effluent Technologies, V. 2, Issue 4, Dec. 2016, pp. 175-184.

63. Safina, C., Perelman, J., Pesky Plastic: The True Harm of Microplastics in Oceans, National Geographic Blog, April 4, 2016.

64. Salish Sea Toxic Monitoring Review, Puget Sound Ecosystem Monitoring Program, A Selection of Research. 2017.

65. Schwartz, T., Herring, B., et al, Membrane Bioreactor Performance Compared to Conventional Wastewater Treatment, Water Technologies and Solutions, Technical Paper (undated).

66. Scientific Opinion on Norovirus (NoV) in Oysters: Methods, Results and Control Options, European Food Safety Authority Journal, 2012:10(1):2500.

67. Seltenrich, N., New Link in the Food Chain? Marine Plastic Pollution and Food Safety, Environmental Health Perspectives, 2015 Feb:123(2): A 34-31.

68. Sharville, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H., and Olivieri, A., Risk Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems, prepared by the National Water Research Institute for the Water Environment and Reuse Foundation, 2017.

69. Stantec Consulting Ltd., Bowser Village Wastewater Servicing Design Report, Regional District of Nanaimo, April 2017.

70. Talvitie, J., Mikola, A., Koistinen, A., Setala, O., Solutions to Microplastic Pollution—Removal of Microplastics from Wastewater Effluent with Advanced Wastewater Treatment Technologies, Water Research, V. 123, Oct. 15, 2017, pp. 401-407.

71. Taylor, F., Harrison, P., Harmful Algae Blooms in Western Canadian Coastal Waters,University of BC.

72. University of Wisconsin News, Do Treatment Plants Effectively Remove Drugs, Hormones from Wastewater? Aug. 25, 2004.

73. US Environmental Protection Agency, Shellfish Harvesting/Health of the Salish Sea, Ecosystem Report, March, 2018.

74. Virus Hazards from Food, Water and other Contaminated Environments, FEMS Microbiology Reviews, July 2012, V.6, issue 4, pp.786-814.

75. Wastewater Pollution, Environment and Natural Resources, Government of Canada, 2014.

76. Water Resources Research Center, University of Arizona, Emerging Contaminants, 2013.

77. Xagoraraki, I., Ziqiang, Y., Zhassulan, S., Fate of Viruses in Water Systems, Journal of Environmental Engineering, July, 2014.