Entrance of paper mill effluent chemicals into ecosystems and their subsequent biomagnification and interaction with humans—a review.

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Abstract.

The pulp and paper manufacturing process has become a necessary part of modern and industrial life around the world, and the looming presence of paper mills can be felt in environments of countless countries. Left unchecked, the pollutants released from paper mills in the effluents would destroy the water, land, and air around the paper mills. Although many treatment processes are available to paper mills to treat their effluents, the quality of wastewater leaving mills is often questionable. Studies have been conducted to determine the impact on the environments and organisms surrounding the paper mills, especially bodies of water and their inhabitants. Like many other chemicals that are present in the ecosystem, pollutants introduced by paper mills are capable of entering the food web, at which point many will undergo biomagnification, increasing in concentration as it moves up the food chain, creating a landslide effect on sensitive ecosystems. Humans, the cause of the pollution, are not free from its effects, as the chemicals present in the water are harmful to the physical and economic health of communities around or downstream of paper mills.

Introduction.

Paper mills present a source of highly concentrated chemicals being added directly to the surrounding environments. Many of these chemicals are known to be toxic to animals and humans. Some have been proven genotoxic, or DNA destroying (Pokhrel & Viraraghaval, 2004, p. 41). Such chemicals are usually fatal or cancer causing on contact, especially chronic contact as one would expect from presence in a water source. Beyond the possible impacts chemicals have on the individual organisms that they contact, they have the possibility to completely reshape or destroy the environments surrounding the paper mills. According to Eric Mullen, a commercial diver employed at Crofton Diving Corporation that has worked with the

International Paper mill in Franklin, Virginia, most paper mills, such as the mill in Franklin, have special procedures in place should a meltdown occur and untreated chemicals exit the plant into the surrounding environment (personal communication, November 4, 2014) (Appendix). Chemicals are not added directly from the plant to the environment, treatment does occur in order to remove as many chemicals from the wastewater. The companies that own the paper mills, however, usually search for the cheapest, fastest, and most efficient treatment processes in order to streamline their production process and reduce costs, increasing their profits. Some treatments that have been developed, or at least proposed, seem a bit unconventional, but have proven to be effective in their treatment of wastewater. Paper mills have begun using plants in the wastewater, effluents and the surrounding bodies of water to soak up the chemicals and diminish their impacts on the environment. The chemicals, should they be left unchecked, move into the ecosystem, enter into the food chain, and work their way up until it impacts humans in the communities surrounding and downstream from the paper mills.

Processes and chemicals used in paper mills.

Paper mills begin the process of converting raw materials—wood, straw, grasses, bamboos, canes, and reeds (Pokhrel & Viraraghaval, 2004, p. 38)—into pulp and eventually paper with the addition of vast amounts of chemicals. These chemicals are taken away from the intermediate and final products with the wastewater, which becomes known as effluent once it has been contaminated with chemicals. The effluent, after being treated, is released into the environment; into rivers, lakes, and oceans (Pokhrel & Viraraghaval, 2004, p. 37).

Pollutants enter the effluent at several points in the paper making process, beginning with the pulping process. At this stage in the process, resin acids, unsaturated fatty acids, diterpene alcohols, juvaniones, chlorinated resin acids, and other chemicals are added to the water that becomes the effluent, and, eventually, the wastewater of the plant. Pulping produces the largest amount of wastewater and pollutants of all the steps in the paper making process. While mechanical pulping is possible with low chemical use and high yield, it creates lower quality pulp, which would produce lower quality paper. Chemical pulping has a yield about half that of mechanical pulping, but produces a higher quality pulp through chemical treatments (Pokhrel & Viraraghaval, 2004, p. 38). The second stage of pulp and paper production, bleaching of the pulp, also adds a large amount of pollutants to the effluent, including chlorate ions, dioxins, furans, chlorophenols, acetone, and many others, which are considered some of the more dangerous chemicals added to the surrounding ecosystems (Pokhrel & Viraraghaval, 2004, p. 39). All of these chemicals are thought to harm the environments and organisms surrounding the paper mills, if left untreated in the effluent. Four categories of treatment processes are available for paper mills to treat their effluents before releasing the wastewater into the environment: physiochemical, biological, fungal, and integrated. Each category has several different process types, each specialized at removing certain chemicals from the effluent with varying rates of success.

Physiochemical treatment processes (Table 1) are usually used to remove suspended particles, colors, or toxic compounds in the effluent through processes such as sedimentation, floatation, coagulation and precipitation, adsorption, chemical oxidation, membrane filtration, and ozonation (Pokhrel & Viraraghaval, 2004, p. 43). Sedimentation is currently the process most commonly used in paper mills and has the ability to remove most of the suspended solids (SS) in the effluent (Pokhrel & Viraraghaval, 2004, p. 51). Coagulation is the preferred method to remove color from effluent, but it is also capable of reducing chemical oxygen demand (COD), total organic carbon (TOC), and absorbable organic halogens (AOX) (Pokhrel &

Viraraghaval, 2004, p. 51). Adsorption can be used to remove color, COD, and AOX, but it is expensive and thus not readily applicable to use in full scale paper mills (Pokhrel & Viraraghaval, 2004, p. 51). Membrane filtration can result in almost complete reduction in color, TSS, and AOX, but suspended wood chunks can damage the membrane, adding to the already high cost of the process (Pokhrel & Viraraghaval, 2004, p. 52). Ozonation and other chemical oxidants can be used to reduce COD, Ethylenediaminetetraacetic acid (EDTA), and AOX to almost normal levels, as well as TOC and color, but the process is also expensive and difficult to implement in paper mills (Pokhrel & Viraraghaval, 2004, p.51).

Treatment process	Parameters											
	TSS		COD		TOC		AOX		Color		Lignin/Resin* or Fatty# acid	
	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (Pt–Co)	% Removal	Influent (mg/l)	% Removal
Coagulation:												
Polyelectrolyte	3620	100	4112	55.65	–	–	–	–	4667.5	82.58	480	98.91
Chitosan	–	–	–	–	–	70	–	–	–	90	–	–
PE/PEI	–	–	–	–	–	30	–	–	–	80	–	–
Alum	–	–	–	–	–	40	–	–	–	80	–	–
Adsorption:												
Charcoal #1	–	–	–	–	–	–	–	–	3.9 mg/l	98.13	–	–
Coal ash #2	–	–	–	–	–	–	–	–	3.9 mg/l	98.5	–	–
Fuller earth #3	–	–	–	–	–	–	–	–	3.9 mg/l	99.21	–	–
Activated coke #4	–	–	2126	>90	–	–	80.2	>90	2300	>90	–	–
Oxidation: (Wet oxidation)	–	–	10,000~19,000	80	3500~4100	80	–	–	–	–		
(Ozone + Fenton)	–	–	–	–	–	–	–	–	–	~100		
Ozonation:												
Ozone + UV	–	–	~550	82	–	–	–	–	–	–		
Photocat. + ozone	–	–	515	85	306	88	27.7	92.5	250	100		
Photocat. + ozone	–	–	3700	57.5	1380	38	69.8	50	7030	65		
Membrane:												
Ultrafiltrtion	–	–	–	85–90	–	–		85–91		93–98		
Nanofiltration	–	–	–	–	–	–	–	93–96		99.2–99.9		
Dissolved air + UF	397	100	–	–	828	65	–	–	1747	90		
Microfiltration + UF	397	100	–	–	828	54	–	–	1747	88		

Table 1. Physiochemical processes reviewed by Pokhrel and Viraghaval (2004, p. 48) and their percent removal of chemical components of paper mill effluent.

Biological treatment (Table 2) employs living organisms, often microbes, to break town suspended or toxic substances in the effluent before it is released into the environment. Biological treatments that were tested or are used by paper mills can be broken into aerobic treatments, those that require exposure to oxygen, and anaerobic treatments. Aerobic treatments in the activated sludge process, aerated lagoons, and aerobic biological reactors (Pokhrel & Viraraghaval, 2004, p. 44). Activated sludge is the most commonly used secondary process in paper mills and is capable of removing all types of pollutants, including almost all BOD and COD, but can typically remove less than half of AOX (Pokhrel & Viraraghaval, 2004, p. 52). Aerated lagoons are capable of removing almost all of BOD and chlorinated phenolics as well as the majority of COD and AOX (Pokhrel & Viraraghaval, 2004, p. 52). Aerobic biological reactors are often reported to have high removal rates for organic compounds in the effluent, including complete removal of methanol and almost complete removal of COD. Combination of different reactors were also attributed with the removal of TOC, BOD, lignin and resin acids, SS, and AOX (Pokhrel & Viraraghaval, 2004, p. 45). Anaerobic treatments include anaerobic contact reactors, which are able to remove almost all BOD and the majority of COD (Pokhrel & Viraraghaval, 2004, p. 52).

Performance of biological treatment processes

Treatment process	Parameters							
	BOD		COD		Methanol		Color	
	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal
Biological reactors								
HRC (TMP Mill)	1150	98	3340	79	–	–	–	–
Total plant efficiency	1490	99	5000	86	–	–	–	–
MBBR (HRT 4.5 hrs)	–	65–75	–	85–95	–	–	–	–
SBR	–	98	–	85–93	–	–	–	–
Anaerobic (GAC)	–	–	1400	50	–	–	1300	50
Kraft mill Windsor	1429[a]	69	2036[a]	59	1095[a]	84	–	–

[a] Unit in g/d.

Table 2. Biological treatments reviewed by Pokhrel and Viaraghaval (2004, p. 49) and their percent removal of chemicals from the paper mill effluent.

Fungal treatments (Table 3) employ the use of different strains of fungi in order to digest or precipitate out chemicals or colors from the effluent. Different fungi species, such as *Pencillium* sp., *T. versicolor*, *P. chrysosporium*, *P. sanguineus*, *P. ostreatus*, and *H. annosum* were effective at different levels in removing different pollutants form the effluent (Pokhrel & Viraraghaval, 2004, p. 46). *Pencillium* sp. was able to remove nearly half of AOX as well as the color from effluents after being left in solution for only two days (Pokhrel & Viraraghaval, 2004,

p. 46). *T. versicolor* and *P. chrysosporium*, two white rot fungi, were able to reduce the color as well the COD in the effluent (Pokhrel & Viraraghaval, 2004, p. 46). *P. chrysosporium* in combination with other white rot fungi—*P. sanguineus, P. ostreatus*, and *H. annosum*—lowered the lignin content of the effluent as well as reduction the majority of color and COD (Pokhrel & Viraraghaval, 2004, p. 52).

Performance of fungal treatment

Treatment process	Parameters					
	COD		Lignin		Color	
	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal	Influent (mg/l)	% Removal
White rot fungi	39,012	40.74	2870	16.38	34,940	34.49
White rot + surfactants	39,012	75.35	2870	65.84	34,940	81.29
White rot (*T. versicolor*)	–	77.7	–	–	1875	93.8

Table 3. Fungal treatment processes reviewed by Pokhrel and Viraraghaval (2004, p. 47) and their percent removal of chemicals from the paper mill effluent.

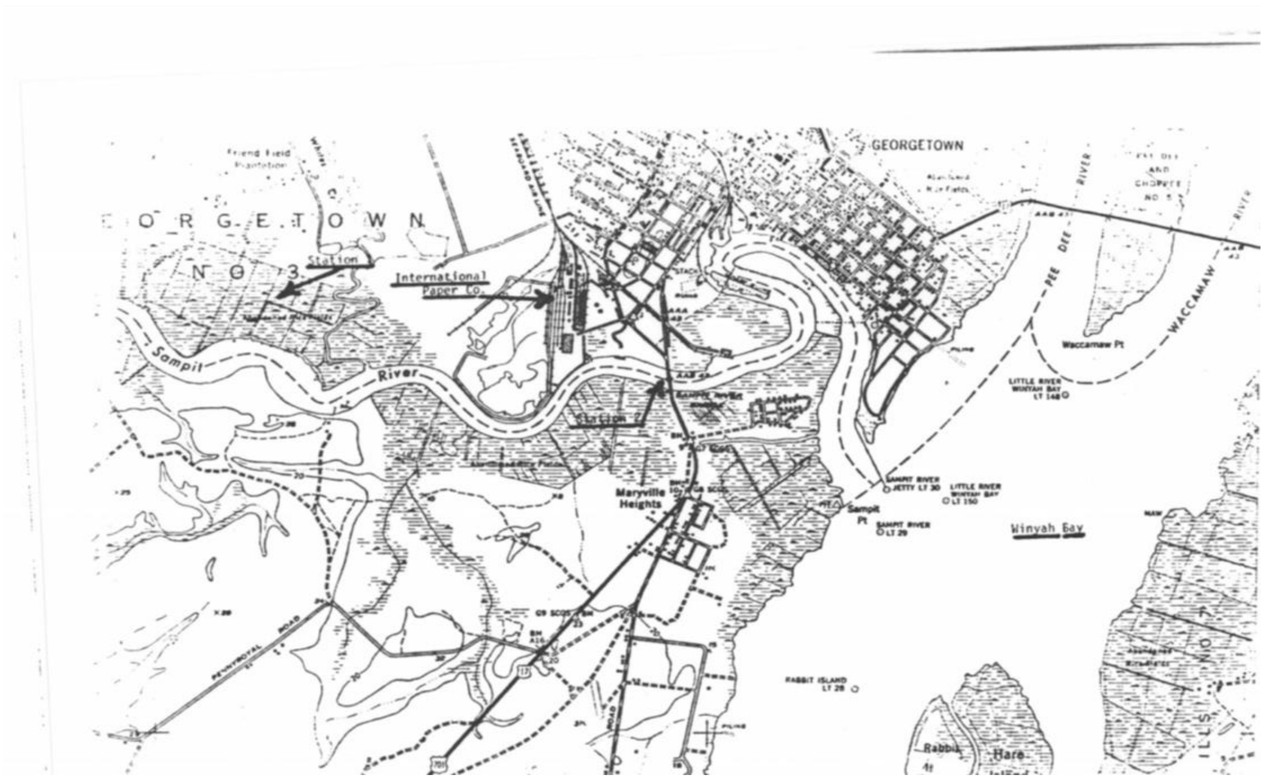
Integrative treatment processes include are hybrid systems of at least two different processes from the same or different classifications of processes (Pokhrel & Viraraghaval, 2004, p. 47). The most effective combinations were found to be combinations of two or more physiochemical processes and combinations of physiochemical and biological processes (Pokhrel & Viraraghaval, 2004, p. 52). Examples of physiochemical combinations included coagulation and oxidation, which removed most of COD, color, and lignin; ozone and biofilm reactors removed the majority of COD; chemical oxidation and ozone removed almost all wood extracts and about hald of COD; and air flotation with chemical precipitation, which removed the majority of SS, BOD, COD, phosphorous (P), and nitrogen (N) (Pokhrel & Viraraghaval, 2004, p. 47). Physiochemical and biological combinations include activated sludge and ozonation, which removed almost all COD and BOD (Pokhrel & Viraraghaval, 2004, p. 47).

Entrance of chemicals into the food chain.

Generally for pulp and paper mills, when waste is improperly discarded from the factory the method is either through the emission of aerosols and other light, buoyant materials or disposal of waste into the nearby environment (sludge and effluents) (Ali and Sreekrishnan, 2001, Table 1). For this paper we will be focusing on the liquid byproduct that enters the riverine system, although it should be noted that airborne waste product is capable of accumulating in such bodies of water. Once discarded on land, mill effluents will find their way into a fluvial channel, either by being dumped directly into the current and nearby tributary or entering the channel as runoff from land dumping. In the case of International papers, the mill directly dumps waste discharge into the Sampit River, which feeds into Winyah Bay (Figure 1). The discharge mixes with the current and moves along the channel.

Among non-toxic water discharges, hazardous material is released out as a means of disposal. There are different types of hazardous chemicals released, but most are categorized as organochlorines. While organochlorines do exist naturally, the persistent type produced and disposed of in pulp effluent, under the name chlorinated dioxins. Chlorinated dioxins, when concerned with hazardous pulp effluents, fall under into two families, chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans (Oanh et al., 1999, p. 303). Chlorinated dioxin has been has been shown to have mutagenic tendencies, causing damage to genetic structures to organisms in contact with the chemical (Ali and Sreekrishnan, 2001, p. 176, 181). Certain chlorinated dioxin have been categorized as a carcinogenic substances, such as 2, 3, 5, 7-Tetrachlorodibenzo-p-dioxin (TCDD) and 2, 3, 5, 7-Tetrachloro dibenzofurans (TCDF) (Oanh et al., 1999, p. 303; Ali and Sreekrishnan, 2001, p. 176, 181). During the 1990s, International Paper effluent underwent scrutiny as it contained concerning levels 2, 3, 5, 7-TCDD and trace amounts of 2, 3, 5, 7 Tetrachloro dibenzofurans. Researchers found from 17.0 to 46.7 ppt of the chemical within six double crested cormorants (U.S. Fish and Wildlife Service, 1991, p 3). However, it is currently unknown if these chemicals are still present within the effluent of the Georgetown pulp and paper mill. Whether the two chemical dioxins, or other hazardous chemicals like them, still persists in the water column pends water analysis of the Sampit River and the Winyah Bay system.

For chemicals to enter the biological community of a riverine system in large quantities, certain interactions must occur between the biological and chemical. Chemicals mixed into the water can enter the food web through three ways: from the uptake of water (bioconcentration), exposure to contaminated sediments, and the absorption food and suspended particles (López, 2003, p 754). While direct uptake from the water higher up the food chain can influence the accumulation of chemicals in a riverine ecosystem, the entrance through biofilms is of even more interest. Biofilms are large interacting groups of microorganisms in a mucopolysaccharide matrix that tend to adhere to each other and environmental surfaces. These communities can be made up of bacteria, fungi, algae, and other microorganisms that stay in close proximity to one another (Sabater et al., 2007, p 1425-6). Sabater et al (2007) consider them to be the biological interface between chemicals and accumulation in higher trophic levels (1426). How this interface is accomplished is mainly due to the biofilm's membrane. Early in biofilm development, exopolysaccharides (EPSs) are utilized. EPSs differ from later membrane structure as they include proteins and lipids, as well as polysaccharides, and assist in increasing cell to cell joining. This creates a tight matrix which allows for various substances to



bind to the EPS. Adsorption is key to this process as large chemical molecules become snared in the matrix and weak molecular contact keep the chemicals fastened (Sabater et al., 2007, p 1426). In this way, as higher trophic grazers consume the biofilm, the chemicals trapped in the matrix can travel further up the trophic web. In the Sampit River, the possibility that hazardous chemicals could enter the ecosystem through this means is not to be dismissed, even if it is the case that toxicants are no longer in the effluent. As the hazardous chlorinated dioxins and other toxicants have been produced in the past, they could accumulate in the sediments and, through biofilm interaction, enter the food web. From effluent to biofilm, such dissolved chemicals are allowed to further accumulate in the Sampit River system.

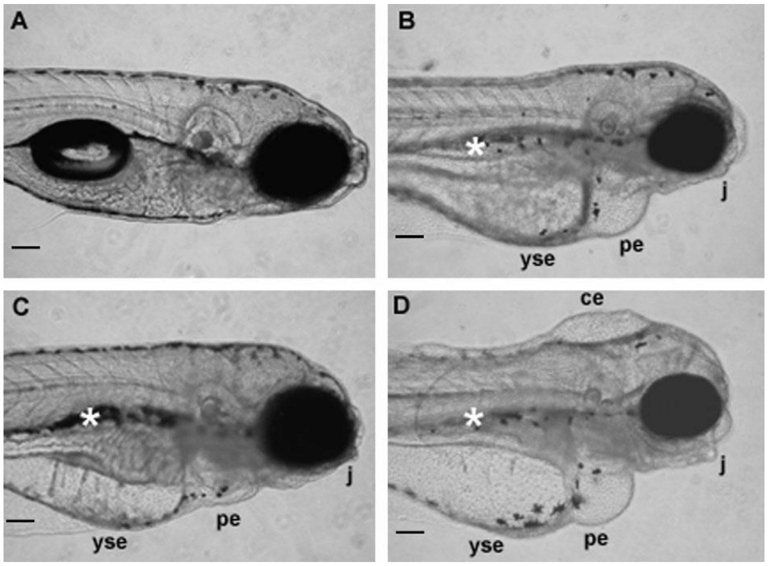
Biomagnification of chemicals within the food chain.

Pulp paper mills release toxic organic compounds into waterways in the form of effluent. Some compounds found in the effluent can have a negative impact on the health of organisms that inhabit the surrounding areas. 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD) is a highly toxic dioxin found in paper mill effluent. TCDD. Factors such as: bioconcentration, bioaccumulation, and biomagnification contribute to the increased concentrations of dioxin in organisms near paper mills. High levels of dioxins can have adverse effect on an organism's reproductive success.

Bioconcentraion is the path in which chlorinated hydrocarbons follow to enter the lower trophic levels. This route refers to the absorption of chemical compounds by organisms via diffusion. Dioxins found in paper mill effluent are heavy relative to their environment. For this reason they tend to sink and become part of the substrate. The toxins in the sediment are then

Figure 1 depicts a map of the Sampit River and Winyah Bay system from the U.S. Fish and Wildlife Service (1991) study. International Paper is positioned upstream of the Winyah Bay, directly on the Sampit River before it encounters Georgetown.

absorbed by organisms that use diffusion as a respiratory, or digestive pathway. These organisms usually consist of plants and microscopic invertebrates. Pelagic organisms absorb smaller amounts of TCDD than benthic organisms. This is because there tends to be more toxic compounds in the sediment than suspended in the water column. A study done by Helene Loonen et al. (1996) suggests that, "concentrations of 2, 3, 7, 8-TCDD and OCDD in oligochaetes are higher after exposure to sediment than after exposure to overlying water." The Bioconcentraion of TCDD in benthic organism will lead to bioaccumulation in predatory organism, as well as biomagnification of dioxins further up the food chain.



Bioaccumulation is caused by the accumulation of toxins over an organism's lifetime. Fish and crustaceans that feed on small organisms like oligochaetes, accumulate greater amounts of toxins each time they consume a contaminated organism. TCDD is a lipophilic compound, meaning it attaches to the fatty tissues of organisms. However, Dioxins do not affect the organism directly, but can cause reproductive problems. This is the case in a study done on zebrafish. "Adult zebrafish are fairly resistant to the toxic effects of TCDD, chronic exposure to sub-lethal concentrations adversely affected reproduction as measured by impacts on the ovary, as well as offspring health and survival" (King et al. 2005). The deformations of offspring can be seen in (Figure 2). As bioaccumulation occurs in smaller fish and crustaceans the toxins are absorbed by predator’s fatty tissues as they consume contaminated prey. The exponential increase in toxin concentrations through predation is known as biomagnification.

Biomagnification occurs when predators feed on organisms that have accumulated toxins. The concentrations increase exponentially or magnifies due to bioaccumulation of dioxin via consumption of organisms lower on their respective food chain. Upper trophic levels contain the highest concentrations of dioxins due to biomagnification. Marine bird species exhibit biomagnification. This is because marine birds consume large amounts of fish that have accumulated high concentrations of dioxins. A study on the reproductive success based on the location of nests relative to pulp mills. Egg samples were taken from upstream of a paper mill, downstream of a paper mill, and in a pristine environment (Figure 3). Each egg was tested for dioxins as well as other toxins. Eggs taken from downstream of the paper mill showed a significant increase in [TCDD] (Table 4).

Figure 2. “Representative zebrafish larvae (6 dpf) from females fed diets containing TCDD. Larvae exhibited one or more of the following morphologicalanomalies: Cranial (ce), pericardial (pe), or yolk sac edema (yse), uninflated swim bladder (*), subcutaneous hemorrhage (not shown), shortened jaw (j), and tail necrosis (not shown). Not all larvae were affected.” (King et al. 2005)

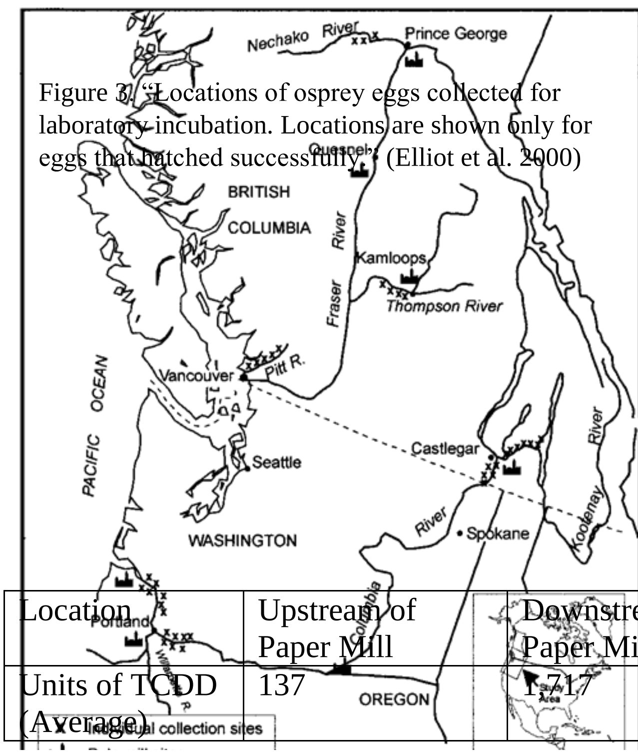


Figure 3. “Locations of osprey eggs collected for laboratory incubation. Locations are shown only for eggs that hatched successfully.” (Elliot et al. 2000)

Location	Upstream of Paper Mill	Downstream of Paper Mill	Pristine Environment
Units of TCDD (Average)	137	1,717	49.25

Table 4. Embryonic levels of TCDD in osprey eggs compared to nest location.

Osprey are an apex predator that have a protective selectively permeable skin. Therefore, diffusion cannot be a means for dioxin to enter the body. Dioxins found in osprey and osprey eggs is most likely due to bioaccumulation. The relatively high concentrations are most likely a result of biomagnification. Biomagnification would occur in the osprey because they feed high on the food chain.

Impact of chemicals on humans.

There are many chemicals in paper mill effluent that can be harmful to humans. Tetrachlorodibenzo-dioxin (TCDD) is one of the most toxic chemicals that can be found in paper mill effluent and is most commonly consumed by eating contaminated fish or drinking contaminated water. Dioxins are some of the most toxic chemicals known to man and are supposed to be limited to small amounts in paper mill effluent, the problem is that even small amounts can be harmful to humans. The tolerable daily intake of dioxins is 1-4 picograms (1.0x10^-15grams) per kilogram body mass (Leeuwen, 2000). TDCC has been proven to be a very aggressive carcinogen. It also impairs reproductive health and can render healthy adults sterile. Even with health insurance, cancer treatment can cost anywhere from $100 to $15,000 out of pocket for each treatment (American Cancer Society, 2012). Treatment options vary, but many of those options require multiple treatments every month for the duration years if necessary.

Mercury is another harmful element found at high quantities in paper mill effluent. Exposer to mercury has been shown to cause tumors, birth defects, and in severe cases death. Mercury poisoning, hydrargyriasis, is a form of heavy metal poisoning and is just one outcome of contact with mercury. Hydrargyriasis damages major internal organs causing sensory impairment, kidney failure, and lung disease (NRDC, 2014). Some other toxins that have been shown to effect humans and are found in paper mill effluent are nitrite nitrogen, chlorides, transition metals, chelating agents, and dioxins (Table 5).

Parameters	Untreated effluent	Chemically treated effluent
Temperature	41.77±1.30	29.47±0.29
pH	8.83±0.17	7.23±0.15
Conductivity	1800±5.77	1689.87±0.59
TSS	1018±11.53	780.00±1.15
TDS	2091.67±8.33	1599.00±1.15
DO	1.67±0.09	3.33±0.09
BOD	520.33±0.88	93.88±0.82
COD	1196.00±3.06	216.93±0.58
Chlorides	597.33±1.45	399.67±1.00
Nitrite nitrogen	2.80±0.10	0.37±0.06
Nitrate nitrogen	3.10±0.06	1.03±0.09
Phosphate (PO_4^{-3})	0.60±0.01	0.29±0.01
Sulphate (SO_4^{-2})	216.85±1.03	119.80±0.10
Potassium (K)	68.63±0.68	58.20±0.20
Mercury (Hg)	0.46±0.02	0.37±0.02
Copper (Cu)	0.23±0.01	0.13±0.01

Table 5. Concentrations of toxins measured in milligrams per liter, degrees Celsius, and mho per centimeter (Swayamprabha et al. 2012)

The reason these toxins are so harmful is because they are being pumped into the rivers people use regularly. People who use the river for recreational purposes have a higher risk of coming into contact with infected water. Direct contact with the water while swimming causes rashes and infections of the eyes and ears. Handling contaminated fish from the river causes skin rashes and can cause cuts that get infected. Boating on the river can even be hazardous because the spray from the wake can infect eyes and exposed skin. Any contact with the contaminated water of the Sampit River, whether direct or indirect, can cause serious medical issues.

The highest risk of becoming ill from these toxins is by eating food that came into contact or drinking the contaminated water. Washing food with contaminated water from a hose or well that is sourced from the river can cause severe illness because the toxins attach to the solid food. Drinking contaminated water causes ulceration of internal organ linings, severe diarrhea, and if left untreated can end in death. The greatest threat of coming into contact with these toxins is by eating fish from the contaminated river. The fish of the river are so toxic because they have spent their entire life swimming and eating in the contaminated waters. Through biomagnification the larger fish slowly collect the toxins from all the organisms they eat and become even more dangerous to eat. Eating these fish is even more dangerous than drinking the water directly because the toxins of the river have concentrated themselves in the flesh of the fish (NRDC, 2014).

Making contact with the contaminated water should be avoided at all times. Swimming should be prohibited at any point downstream of the paper mill and for five miles upstream. Wake should be kept to a minimum to reduce exposure to the contaminated water from spray. If going out onto a boat is unavoidable, exposed skin should be covered and eyes should be protected (NRDC, 2014). Doing these simple things when there is a chance of coming into contact with contaminated water will reduce the risk of illness due to exposure.

Fish from the river that are caught within 50 miles of the paper mill should never be eaten. Fish are not stationary organism and regularly swim upstream into non-contaminated water. While fishing recreationally, exposed skin should be covered and protective eye wear should be used. When handling fish from the river heavy duty gloves should be worn to ensure safety from being pricked by spikes and from being bitten by predatory fish. Fish with major deformities should be photographed and reported to local Department of Natural Resources.

If a home or business is situated near the river, water should never be sourced from the river. Water is sourced from the river, and there is no way of avoiding the use of the water, it should be filtered as well as possible. The water should never be used to wash food even after being filtered because there may still be traces of the toxins even after filtration (Murray, 1992).

Water that is sourced from the contaminated river should never be consumed under any circumstances.

The most effective way to protect people from the toxins being pumped into the Sampit River is to clean the river. The first step to a clean river would be to preserve the plant life in the river. Studies have shown that water remediation by plant life is more effective in removing toxins than any other form of chemical remediation technique (Swayamprabha, 2012). If plants were allowed to grow unimpeded by longshore construction there would be a higher rate of toxin filtration. Reducing the wake of boats would also increase the survival rate of vital plants that remediate the toxins in the river. Once this is accomplished there could be programs set up to plant more native plants and ensure they grow to help clean the river as well.

Conclusions.

Chemicals from paper mills make their way into the environment through the wastewater that is created by the pulp and paper manufacturing processes, becoming effluent. Over time, however, paper mills have created less wastewater, reducing the amount of effluent that is released into the environment (Pokhrel & Viraraghaval, 2004, p. 42). Internal procedural changes and pressure from legislatures and environmental activists are also pushing paper mills to decrease the amount of water used, creating hopes for a more environmentally friendly manufacturing process in the future. Some research is even being conducted into the feasibility of reusing water from the pulp and paper manufacturing process in order to reduce environmental stress created by paper mill wastewaters (Gunderson, 2010). Throughout the pulp and paper making process, new chemicals are added to the wastewater, accumulating into an extremely toxic effluent that has been proven to have serious negative effects on the surrounding environment and its inhabitants. The effluent is treated, however, to prevent raw wastewater from leaving the mill. These technologies are constantly evolving, creating more efficient and effective processes to allow paper mills to remove more chemicals in higher concentrations, creating effluent that is safer to be released into the environment. Once the chemicals and particulates have left the paper mills, they usually precipitate as sediments or are taken up by primary producers such as algae, making their entrance into the food chain. Although, concentrations of chemicals are low in the first tiers of the food chain, the bulk of contamination spread out over a large biomass, the pollutants accumulate in higher concentrations as the food chain moves from producers to consumers through biomagnification. Because of these processes, contaminants from paper mills pose the greatest threats to apex predators, species that are usually already struggling. Humans do not escape the harmful effects of chemical contamination brought into the environment by paper mills. Chemicals present in the water are toxic to humans, some even proven to be genotoxic. Communities surrounding the paper mills are also holistically impacted, usually resulting in decreased tourism, recreation, and industry associated with the affected bodies of water. Despite the damage that has been done to the environment, food chain, and communities surrounding paper mills because of the harsh chemicals and wasteful procedures used in the production of pulp and paper, scientific studies and legislative changes present an opportunity to prevent further damage and repair the ecosystems that have been effected.

References.

Ali, M., Sreekrishnan, T.R. (2001). Aquatic toxicity from pulp and paper mill effluents: a review. *Advances in Environmental Research, 5*, 176.

Hazardous effluent waste coming from paper mills contribute different chemicals to fluvial channels. Chemicals such as tannins, resin acid, fatty acids, halogenated compounds (organochlorides), and color derivatives can come from different processes during the production of paper. If left in the system they will decay, yet are still hazardous to the environment. However there are different processes that are conducted to reduce or eliminate the chemicals from the effluent stream

American Cancer Society. (2012). Understanding Radiation Therapy Cost. *Understanding Radiation Therapy, a Guide for Patients and Family.*

Elliott, J. E., Wilson, L. K., Henny, C. J., Trudeau, S. F., Leighton, F. A., Kennedy, S. W., & Cheng, K. M. (2001). Assessment of biological effects of chlorinated hydrocarbons in osprey chicks. *Environmental Toxicology & Chemistry, 20*(4), 866-879.

This study tested for the concentrations of dioxins in osprey chicks in areas affected by paper mill effluent. Scientists hypothesized that osprey chicks down stream of paper mills would have a relatively high concentrations compared to chicks born upstream, and therefore have health issues. After testing the fatty tissue from newly hatched chicks it was confirmed that chicks born downstream did contain higher concentrations of dioxin. However, high levels of dioxins did not affect hatching or growth rates.

Gunderson, J. (2010). *Water Treatment in the Pulp and Paper Industry.* Retrieved from http://www.waterworld.com/articles/iww/print/volume-12/issue-3/feature-editorial/water-treatment-in-the-pulp-and-paper-industry.html

Kim Oanh, N.T., Bengtsson, B.-E., Bætz Reutergårdh, L., Hoa, D.T., Bergqvist, P.-A., Broman, D., Zebühr. (1999). Persistent Organochlorines in the Effluents from a Chlorine-Bleached Kraft Integrated Pulp and Paper Mill in Southeast Asia. *Archives of Environmental Contamination and Toxicology, 37*, 303.

Organochlorines are recorded in the effluent of an unnamed chlorine-bleached kraft integrated pulp and paper mill in an unspecified region of South East Asia. Chemicals found include TCDDs, TCDFs, PnCDFs, HxCDFs, HxCDDs, HpCDFs, HpCDDs, OCDFs, OCDDs, N-TEQs, and PCBs. Researchers compared results to Scandinavian bleaching technologies in 1980 to find that the accumulation of organochlorines is less than the 1980s mill, but still significant (especially compared to western pulp mill practices).

Loonen, H., Muir, D., Parsons, J., & Govers, H. (n.d). Bioaccumulation of polychlorinated dibenzo-p-dioxins in sediment by oligochaetes: Influence of exposure pathway and contact time. *Environmental Toxicology and Chemistry, 16*(7), 1518-1525.

Loonen along with other scientists tested the uptake and elimination rates of TCDD by benthic organisms. It was found that uptake rates were higher and elimination rates were lower in individuals that interacted with sediment. This is because dioxins are heavier than water, and therefore sink. This satisfied the hypothesis that organisms that consumed sediment like the worms in the study would have higher concentrations of dioxins.

López, M.C.C. (2003). Determination of potentially bioaccumulating complex mixtures of organochlorine compounds in wastewater: a review. Environment International, 28, 754.

Organochlorines can accumulate in organisms through various different means. Researchers use a previous research and collected experimental data to discuss chlorine found in industry, chemical bioaccumulation, and chemical methods (such as AOX method and EOX methods). The review expounds upon multiple subject areas and only broadly concludes upon the state of the European chemical industry as a whole and the advantages of EOX testing.

Murray, W. (1992). Pulp and paper: The reduction of toxic effluents. *Science and technology division*. Retrieved November 3, 2014 from http://publications.gc.ca/Collection-R/LoPBdP/BP/bp292-e.htm

This journal went through the process of paper mills and what toxins are found in the paper mill effluent. The journal also concluded which toxins affect humans and how they can make their way into households. Treatments for the effluent both in and outside of the plants were recommended and compared to each other to effectively reduce the toxins reaching citizens that live near the paper mill.

Natural Recourses Defense Council. (2014, January 28). *Mercury contamination: A guide to staying healthy and fighting back.* Retrieved November 3, 2014 from http://www.nrdc.org/health/effects/mercury/effects.asp

Pokhrel, D., Viraraghaval, T. (2004) Treatment of pulp and paper mill wastewater—a review. *Science of the Total Environment*, *333,* 37-58.

The researchers compiled and reviewed a collection of research that had been done on the effectiveness of varying treatments of paper mill effluent. Although the researchers also considered the ecological impacts of chemicals in the effluent, should they be left unchecked or be improperly treated, the focus was on quantitatively assessing the rate at which treatment processes could improve the water chemistry of effluent leaving paper mills. These treatments were also weighed against cost and efficiency to determine if they have a future in being used to treat paper mill effluent.

Sabater, S., Guasch, H., Ricart, M., Romani, A., Vidal, G., Klünder, C., Schmitt-Jansen, M. (2007). Monitoring the effect of chemicals on biological communities. The biofilm as an interface. *Analytical and Biological Chemistry, 387*, 1425-1426.

Chemicals that mix in with water supplies can enter the biological web through the interaction between a system's biofilm. Different chemicals will affect th components (species) of the film in various ways and these cause and effect interactions can be used to more easily detect the chemical in body of water. Researches complied various ways assessment methods to determine the chemical affects and biological response to such chemicals. In addition, the different components of the film will tend react together which is also an advantage of using the biofilm for chemical detection.

Swayamprabha, M., Monalisa, M., Chinmay, P., Hemanta, K.P., Ritarani, D., Santilata, S. (2012). Physico-chemical assessment of paper mill effluent and its heavy metal remediation using aquatic macrophytes—a case study at JK Paper mill, Rayagada, India. *Environ monit assess*,.

The researchers found common aquatic plants to remediate the toxins in untreated paper mill effluent. The concentrations of toxins before and after remediation were compared to show how effective the plants were in removing the toxins from the effluent. The results were also compared to the toxin concentrations after chemical remediation to show how plants were more efficient in remediating the effluent.

Tisha King, H., Hutz, R. J., & Carvan III, M. J. (2005). Accumulation, Tissue Distribution, and Maternal Transfer of Dietary 2,3,7,8,-Tetrachlorodibenzo-<it>p</it>-Dioxin: Impacts on

Reproductive Success of Zebrafish. *Toxicological Sciences, 87*(2), 497-507. doi:10.1093/toxsci/kfi201

This study was performed to determine how TCDD impacted reproduction in vertebrates. For this experiment zebra fish were fed food containing dioxin. As accumulation of dioxins increased there were significant birth defects in larval fish as well as a negative impact on female fish sex organs.

U.S. Fish and Wildlife Service (1991). Dioxin Contamination in Sampit River Winyah Bay System, Georgetown County South Carolina (Study ID# 90-4-060). Washington, DC: U.S. Government Printing Office, 3.

Van Leeuwen, F., Feeley, M., Schrenk, D., Larsen, J.C., Farland, W. (2000). Dioxins: WHO's Tolerable Daily Intake. *World Health Organization*

Appendix.

Eric Mullen was contacted in order to gain information about direct impacts of paper mills on the surrounding environment, as he had worked around and inside of the International Paper mill in Franklin, Virginia as a commercial diver and supervisor for Crofton Diving Corporation, a commercial diving and construction business based out of Portsmouth, Virginia. He was asked if he could give any information about treatment processes he had witness, and after being unable to recall any specific treatment process, described procedure, including the contingency should there be a meltdown or release of untreated chemicals, that he had been informed of while servicing the plant. He was also able to give details about the conditions in and around the paper mill and the effects it had on him and the other divers during their short time working at the mill.