5-2021

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Recommended Citation
Howe, E. (2021). Stormwater Effluent Exerts a Key Pressure on the Salish Sea. In K.L. Sobocinski, State of the Salish Sea. Salish Sea Institute, Western Washington University. http://doi.org/10.25710/vfhb-3a69

07 STORMWATER EFFLUENT EXERTS A KEY PRESSURE ON THE SALISH SEA

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What is Stormwater?

One of the primary terrestrial pressures on the Salish Sea estuarine and marine environment is urban stormwater runoff. When rainfall runs across hard, impervious surfaces, rather than soaking into the soil, it picks up and delivers toxic contaminants directly to nearby streams, rivers, and eventually the Salish Sea. In fact, for most toxic substances, surface runoff is the largest contributing source of loading to Puget Sound (Washington State Department of Ecology & King County 2011).

Unfortunately, the Salish Sea's relationship with stormwater effluent is no outlier; stormwater is the fastest growing cause of surface water impairment in the United States as urbanization transitions forested and other natural landscapes to hard, impervious surfaces (USEPA, 2019). Given that the Salish Sea is expected to house another 5 million people by 2040, stormwater interventions will be necessary in order to break the relationship between urbanization and stormwater-caused ecological degradation.

Fortunately, researchers have uncovered a variety of successful techniques to reduce stormwater impairment of surface and receiving waters, including street sweeping, pervious pavement, and green stormwater infrastructure wherein stormwater is filtered by soil and plant mixtures on its way between the streets and the sea. These interventions are costly (approximately $65-132 billion is needed to restore Puget Sound to hydraulically function like a forest), but the costs of stormwater pollution are high as well: the sickening and deaths of Salish Sea organisms. Annual losses due to one contaminant (polycyclic aromatic hydrocarbon exposure) alone are estimated to be between $4.4 to $12.1 billion (Ecology & Washington State Department of Health 2012; Simmonds & Wright 2014).

Urban stormwater runoff is a two-fold problem, impacting the quantity of water pulsing off the land, as well as the quality of that water. As a result of stormwater's twin problems, urban watersheds and marine receiving waters suffer from "urban syndrome"—a condition that results in low abundance and survival of sensitive aquatic and coastal species (Walsh et al. 2005). Virtually all urban streams and rivers in Puget Sound have been harmed by stormwater pollution (Booth et al. 2004).

Water Quantity

Watersheds with as little as 5-10% impervious surface area, such as rooftops, roads, and paved parking areas, exhibit aquatic habitat degradation as a result of increased surface runoff (Walsh et al. 2005). This changes the timing, magnitude, and frequency of high flow events, making urban streams "flashier" than those with natural surrounding landcover conditions. These hydrological changes cause combined sewer overflow events, flooding, erosion, and scouring of stream and riverbeds. Flashy hydrology disrupts habitat structure and alters the ecology of freshwater ecosystems themselves, but also disrupts larger ecosystem processes in marine environments, such as nutrient flux, organic matter processing, and ecosystem metabolism (Palmer & Rubi 2019). While coastal food webs rely on rivers to deliver organisms, nutrients, and detritus from the land to the sea, these fluxes increasingly result in negative impacts, such as eutrophication, hypoxia, and harmful algal blooms.

Water Quality

In addition to altering hydrological flow regimes in watersheds contributing to the Salish Sea, urban stormwater also delivers a suite of contaminants that severely impact the water quality of streams, rivers, estuaries, and the Salish Sea itself. Urban runoff contains complex and unpredictable mixtures of chemicals, including persistent organic pollutants (e.g., PCPs), heavy metals (e.g., copper, zinc), hydrocarbons (e.g., motor oil, tailpipe emissions, rubber tire particles), nutrients (e.g., nitrogen, phosphorous), pesticides, and pharmaceuticals (Noël et al. 2011). Toxic pollutants entering the Salish Sea may be metabolized in plant and animal tissues, bioaccumulated in tissues, incorporated into sediments, volatized, degraded, or conserved in marine waters.

Toxic Stormwater Impacts

Researchers have documented toxic effects of stormwater exposure for a diverse range of aquatic and marine species, ranging from primary producers to high trophic-level predators. Some effects are sublethal, reducing species fitness and long-term survival. For example, heavy metal accumulation is common among marine macroalgae and eelgrass (*Zostera marina*), reducing photosynthetic function (Lyngby & Brix 1984; Jarvis & Bielmyer-Fraser 2015). Other sublethal impacts of stormwater on marine organisms include the reduction of byssus strength in marine mussels (Gaw et al. 2014), reduced olfactory function in juvenile salmonids (Baldwin et al. 2003), reduced growth and lipid storage in juvenile Chinook (Meador et al. 2006), reduced pathogen resistance in juvenile salmon (Arkoosh et al. 2001), cardiotoxicity in juvenile fish (Incardona 2015), decreased reproductive function and immune response in benthic fishes (Rice et al. 2000), seals (Anan et al. 2002), and Southern Resident killer whales (Washington Department of Fish and Wildlife 2011).

Some effects are acutely lethal, as is the case for adult coho salmon, where pre-spawn mortality rates in urban streams can be as high as 90% (Scholz et al. 2011; Tian et al. 2021). These fish end their years-long journey to the ocean and back with their bellies still full of unfertilized eggs, missing their single chance to spawn. For coho, it appears that pre-spawn mortality is linked to the human transportation network, where contaminants, like tire wear leachates, are generated (Feist et al. 2017; Tian et al. 2021). Development expansion and increasing use intensity of the built environment is thus significantly impacting the long-term viability of local coho populations, with far-reaching ramifications for both freshwater and marine food webs alike. And while it is tempting to focus on lethal impacts to iconic species such as coho, road runoff is similarly lethal to lower trophic level organisms, such as mayfly larvae, sea urchins, and amphipods, which all play important roles in upholding marine, freshwater, and terrestrial food webs (Anderson et al. 2007; Kayhanian et al. 2008; McIntyre 2015).

Rainwater hitting a stormdrain in Seattle, WA
Photo: The Nature Conservancy

Moving Forward—Identifying Where Stormwater Pollution Is Generated on the Landscape

A much-repeated phrase from stormwater managers is "how much and where" do we need to implement stormwater BMPs (Best Management Practices)? This is a difficult question to answer until we identify our ecological and social goals for stormwater management. The amount and spatial configuration of stormwater interception techniques will look very different depending on whether the goal is to meet permit regulations, recover coho salmon, or recover Southern Resident killer whales because biological organisms are susceptible to stormwater contaminants for different reasons, in different locations, at different scales, and at different points in time according to their life history traits (Levin et al. 2020). Incorporating robust monitoring programs, such as MusselWatch, the Benthic-Index of Biotic Integrity (B-IBI), and coho pre-spawn mortality observations, and considering the ecological scales at which different biota operate can help identify the biotic response to stormwater runoff, adding valuable ecological information to stormwater monitoring and loading data.

One starting place to answer the "how much and where" question is to build a predictive map quantifying levels of stormwater pollution generated across the landscape. This type of 'threat' heatmap can be coupled with ecological data to produce action maps for stormwater intervention. We have started building the predictive map; we statistically link local stormwater monitoring data to landuse and land cover characteristics, and then calculate the pollution load using local precipitation patterns at 15-minute timesteps for the 32 different hydrologic response units (soil types, landcover types) existing in Puget Sound. We use Big Data capabilities to model surface hydrology across the entirety of the Puget Sound watershed at a 1 m^2 spatial resolution, and aggregate data at several spatial scales for local, watershed, and regional-scale planning.

Areas with high percent cover of impervious surfaces, such as hard cityscapes, as well as industrial and commercial zones, tend to produce higher pollutant loads than high-density residential, low-density residential, and rural areas, which tend to have less impervious surface cover. Transportation networks—roads and highways—generate very high levels of stormwater contaminants, especially those with higher traffic intensity. Traffic behavior (e.g., congestion points) also plays a role, indicating that a combination of a static landscape structure and dynamic anthropogenic behavior layered atop that structure can combine to create stormwater pollution hotspots throughout the landscape. Once we finish building this baseline heatmap, we can begin to add in the ecological layers to understand exactly where on the landscape stormwater interventions will be most efficient and effective at breaking the link between urbanization and aquatic degradation.

08 CONNECTION TO PLACE: INDIGENOUS LEADERSHIP FOR HOLISTIC RESEARCH, RESTORATION, AND GOVERNANCE IN SƏLILWƏT (BURRARD INLET)

Tsleil-Waututh Nation's Treaty Lands and Resources Department, with contributions from Carleen Thomas, Anuradha Rao, Sarah Dal Santo, Lindsey Ogston, and Spencer Taft

Tsleil-Waututh means "People of the Inlet"; Tsleil-Waututh People were born with a sacred obligation to protect the waters of Burrard Inlet. Our first grandfather was transformed from a wolf into a human being. As he grew into a young man, he became lonely. The Creator gave him a vision that he was to dive off one of the tallest cliffs in Indian Arm, grab two handfuls of sediment from the floor of the Inlet, and bring them back to the beach. Our first grandmother was transformed from that. Our ties to this Inlet run deep. It's important that we hold that responsibility, that as a Nation we gather people around who see our vision, and that our work resonates with their own spirit.

Since time out of mind, Tsleil-Waututh have used and occupied Burrard Inlet and surrounding watersheds. Generations of Tsleil-Waututh people were brought up with the teaching, "When the tide went out, the table was set." About 90% of our diet was once derived from Burrard Inlet and the Fraser River, but today the Inlet is unable to support our needs. Cumulative effects of colonial settlement and development have eroded the ecological health, integrity, and diversity of the Inlet. Urbanization and industrialization have brought a complex cocktail of contaminants, transforming Burrard Inlet from our primary food source into a heavily polluted system. By 1972, sanitation and contamination concerns led to the closure of the Inlet to bivalve harvesting. Tsleil-Waututh Nation (TWN) has a goal to restore the health of the Inlet so that we, and future generations of Tsleil-Waututh People, can once again harvest wild marine resources and continue to practice our cultural and ceremonial activities in a clean and healthy environment. The return of herring and orcas shows us that the Inlet is coming back, but there is more work to be done, and we need to do the work together.

TWN is a leader in weaving western and Indigenous science to inform integrated, inter-disciplinary governance and stewardship of natural systems. The science-based, TWN-led Burrard Inlet Action Plan (BIAP) brought together teams of knowledge holders, researchers, practitioners, decision-makers, and community members to share scientific knowledge about the state of Burrard Inlet, to foster development of a shared vision for environmental stewardship, and to identify actions to improve the health and integrity of Burrard Inlet by 2025 so that:

- healthy, wild marine foods can be harvested safely and sustainably;
- water and sediment are safe and clean for cultural and recreational activities;
- important habitats are productive, connected, and support biodiversity; and
- healthy populations of key species are viable and will continue to persist in the long-term.

Applying an Indigenous lens to re-focus water quality science, monitoring, and decision-making, TWN values are starting to reshape on-the-ground research and water quality policy. TWN, in collaboration with the Province of British Columbia, is leading an