Stream Burial: Patterns and Impacts

Stream burial is a common pattern of urban development that originated in the late 1800s with early urbanization. Over the last 150 years, stream channels across urban areas have been altered, buried, and diverted, creating riverless urban centers called urban stream deserts (Napieralski et al., 2015). These urban stream deserts have been identified in several cities across the U.S. and follow similar patterns of dense population and high percentages of impervious area. These areas often suffer from reduced drainage capacity, increased infrastructure expenses, degraded water quality and diminished aquatic habitat (Napieralski et al., 2015; Jacobson, 2010; Elmore & Kauchal, 2008; Walsh et al, 2005).

Piecing together the historic paths of Portland's streams is an interpretive art as streams have been buried, diverted, culverted and piped while the urban core has been flattened to accommodate growth. Portland's urban core, located in the Willamette Basin, was historically characterized by vast hydrological connectivity and hydric soils with wetlands and lakes supporting abundant aquatic life (Douglas, 1914). Several tributaries from six drainage basin in Portland's urban forest, Forest Park, flow in open channels until they abruptly disappear underground into pipes below railroad tracks and industrial areas before their final destination at the Willamette River. Outside of the urban forests, some streams flow in and out of pipes along their route to the Willamette, while others have been buried completely and combined into the sewer systems.

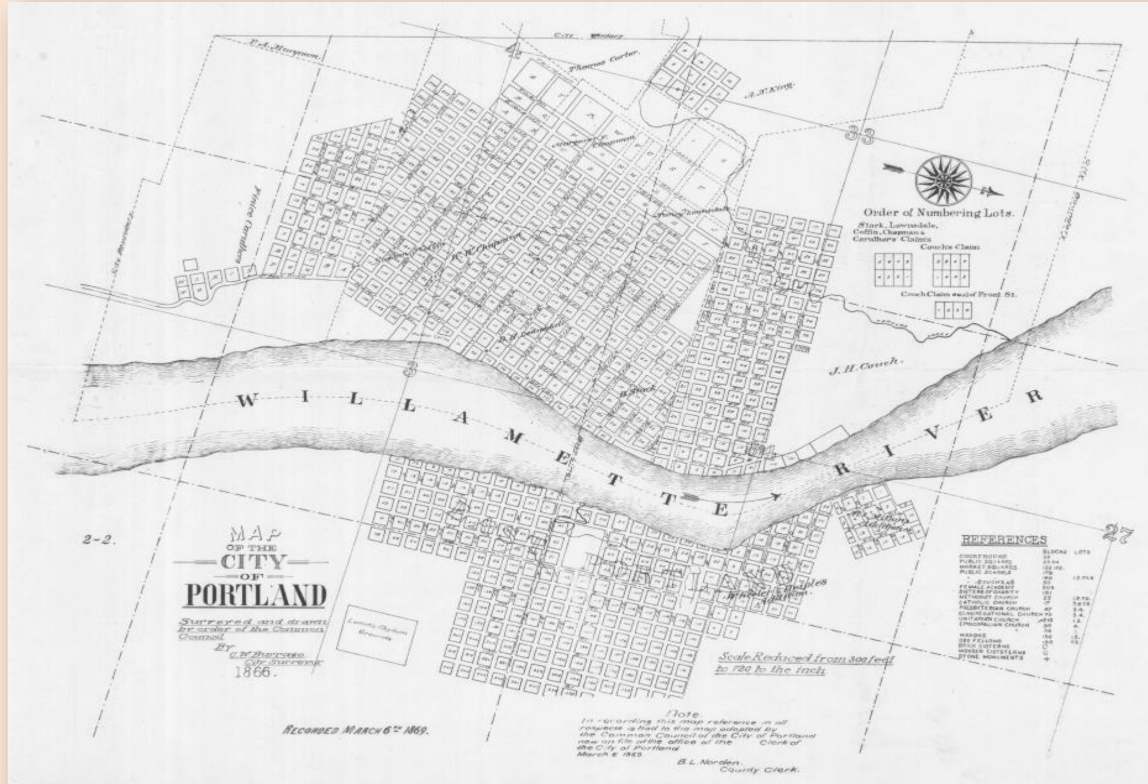
While several streams run underground in Portland's deteriorating stormwater and sewer infrastructure, others are re-routed through backyards and perforated pipes in residential and commercial areas. The 80 year old stormwater/sewer system meant to handle these streams is currently experiencing decreased capacity for runoff resulting in leakage, reduced water quality, combined sewer overflow events, increased flood risk and significant operations and maintenance costs (Broadhead et al, 2015; BES, 2016). The ecological impact of urban development on streams is widely referred to as urban stream syndrome; a condition that includes poor water quality, channel degradation, habitat loss and flashy hydrographs (Walsh et al, 2005). While stream degradation is associated with urbanization, the impacts are not uniform. Stream health is dependent on a variety of factors and will vary by geography and conditions (Tong & Chen, 2003; Walsh et al, 2005).

The purpose of this study is to determine the impacts of urban stream burial in Portland and identify potential for stream daylighting or confluence rehabilitation. This study compares five urban subwatersheds with varying degrees of burial that collect varying types of runoff. The streams will be evaluated based on the comparison of water quality attributes as a reference for the ability to support aquatic life. The results of these conditions can be used not only to support the argument for stream daylighting, but also to prevent further stream burial to vulnerable places.

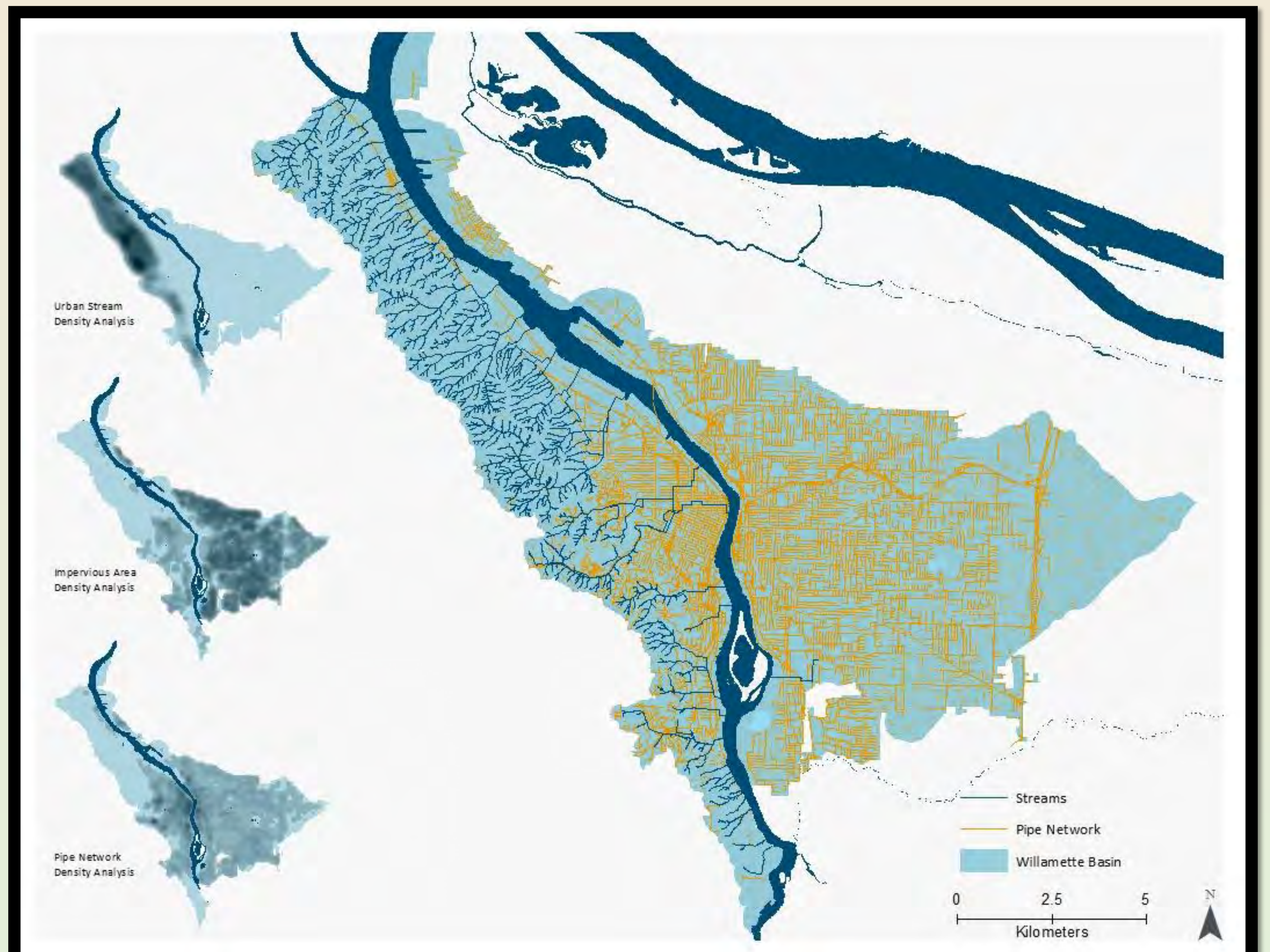
This study seeks to answer the following questions:

1. What are the boundaries of Portland's urban stream desert?
2. What patterns and relationships can be seen between land use and stream burial?
3. Does Stream Burial impact water quality?

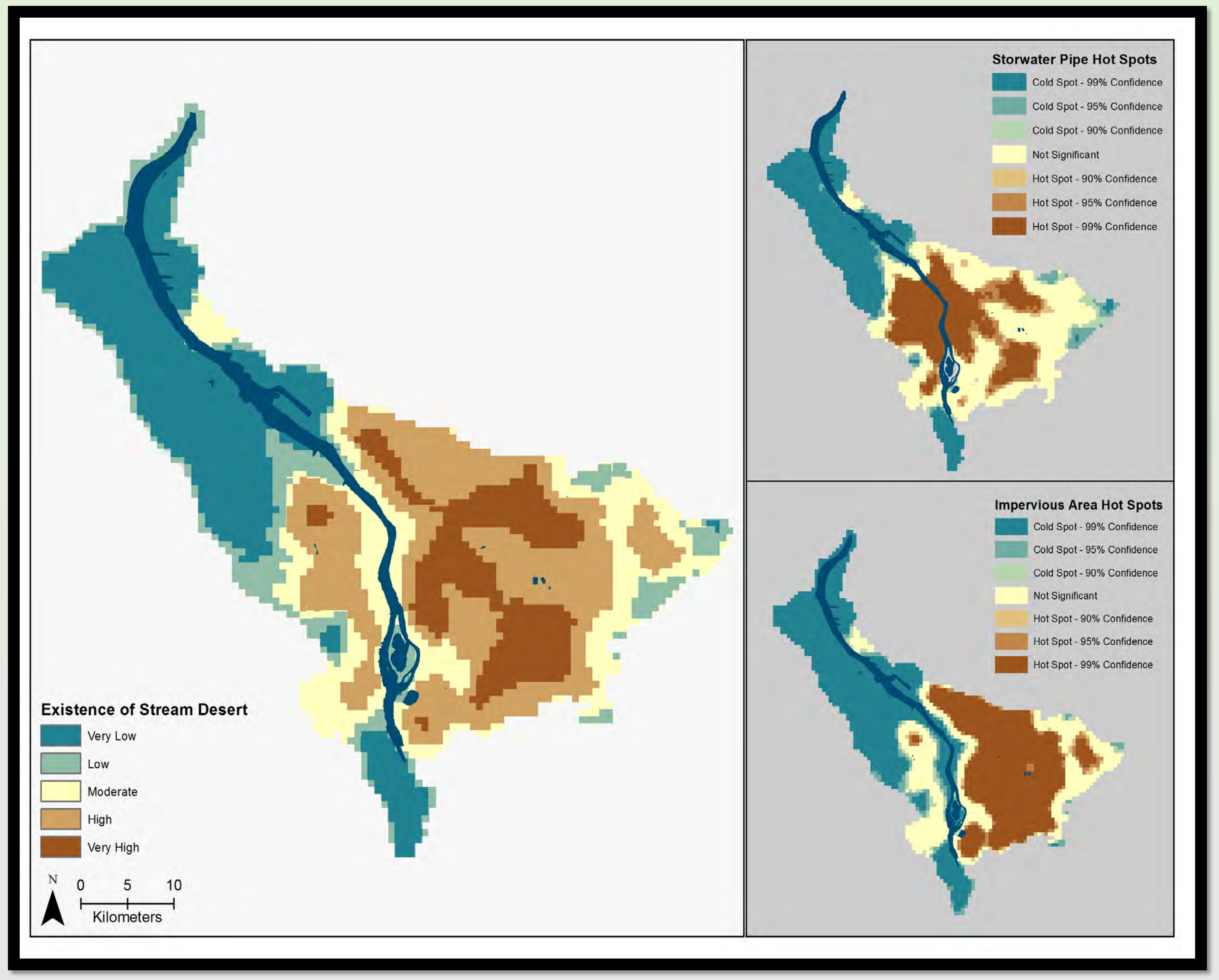
"For more than two hours yesterday Johnson and Tanner Creeks were turned from their beds, and poured their yellow torrents through paved streets, filling cellars of some of the fine residents along the foot of the hill, tearing deep ruts in gutter drains, overturning wooden sidewalks, and temporarily impeding street traffic in many places. So great was the volume of water that people generally thought that the costly sewers that were built to swallow up the troublesome creeks, had burst, and preparations were in progress for a general exodus, when the flood suddenly receded." – The Oregonian, January 13, 1895.



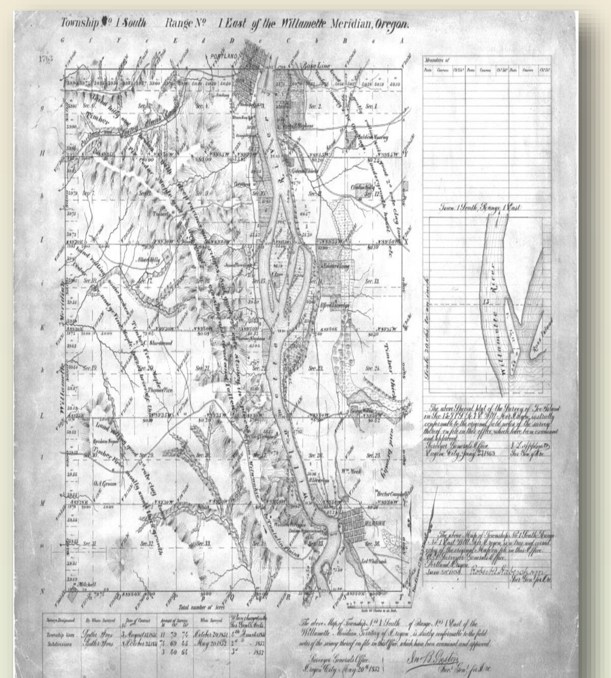
Tanner Creek meanders through historical downtown Portland 1866. Asylum Creek can be seen on the Eastside. Source: The City of Portland



Density overview of streams, pipe networks and impervious area in the Willamette Basin



Portland's delineated stream desert



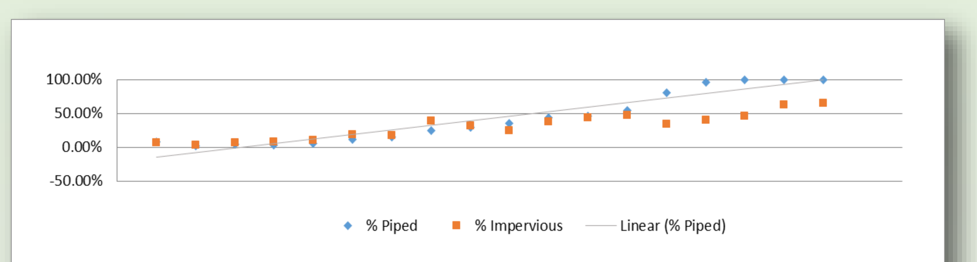
Cadastral Survey 1852. Source: City of Portland

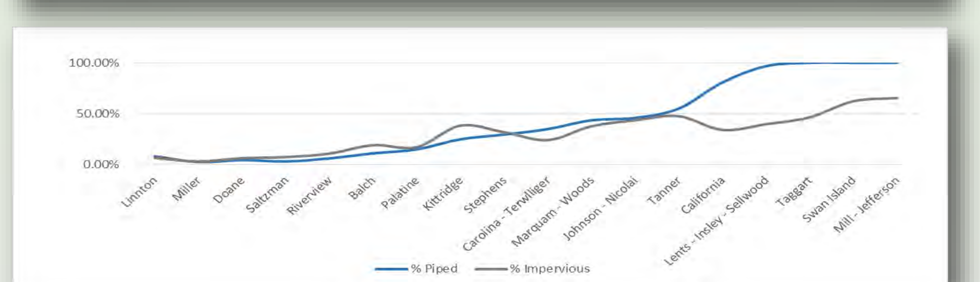
Portland's Urban Stream Desert: Delineation Methods and Analysis

The early attitude toward urban streams is well documented in historic articles and ecological literature. An 1895 newspaper article, *Rush of the Waters,* details an event in which Tanner and Johnson Creeks rush down the west hills of Portland, flooding the main arterials towards downtown and the NW residential area. The article makes mention of the recently built sewers meant to, "swallow up those troublesome creeks (Oregonian; 1895)." The filling and draining of surface waters was supported with legislation like the Swamp Land Act of 1850 and the Flood Control Act of 1936. Such legislation incentivized states to not only fill and drain wetlands for agricultural use and urban development, but also to use and alter waterways to maximize beneficial use. These statutes effectively altered hydrological connectivity under the premise that waterways are unreliable and flawed in their natural state (Robbins, 1978).

Stream burial has long been the solution to the inconvenient reality of water rushing through prime developable land. Portland's development has resulted in the burial of several streams entirely, and most streams partially. Survey maps of Portland between 1852 and 1860 indicate several lost streams. While newspaper articles recount flood events on the westside, explorer's journals include descriptions of the eastside terrain of picturesque rolling lands with hydric soils and plants (Douglas, 1914; Fig X: Survey General's Office, 1852).

Specific development patterns associated with stream burial include the existence of main arterials and freeway networks, establishment of high density residential neighborhoods, and established sewer and stormwater infrastructure. Given the recent increase in population in the Willamette Basin, 11.3% from 2000-2010 and a continued predicted growth rate of 1.7% (US Census 2015; 2010), there is a growing demand for high density housing, updated stormwater and sewer systems, and expansion of main arterials. Such factors (impervious area and piped streams) are significantly correlated with stream burial. A Pearson product-moment correlation coefficient was computed to identify the relationship between impervious area and the percent of piped streams across 18 subwatersheds in the Willamette Basin. Results indicated a strong positive correlation ($r = 0.87$) between the two variables.

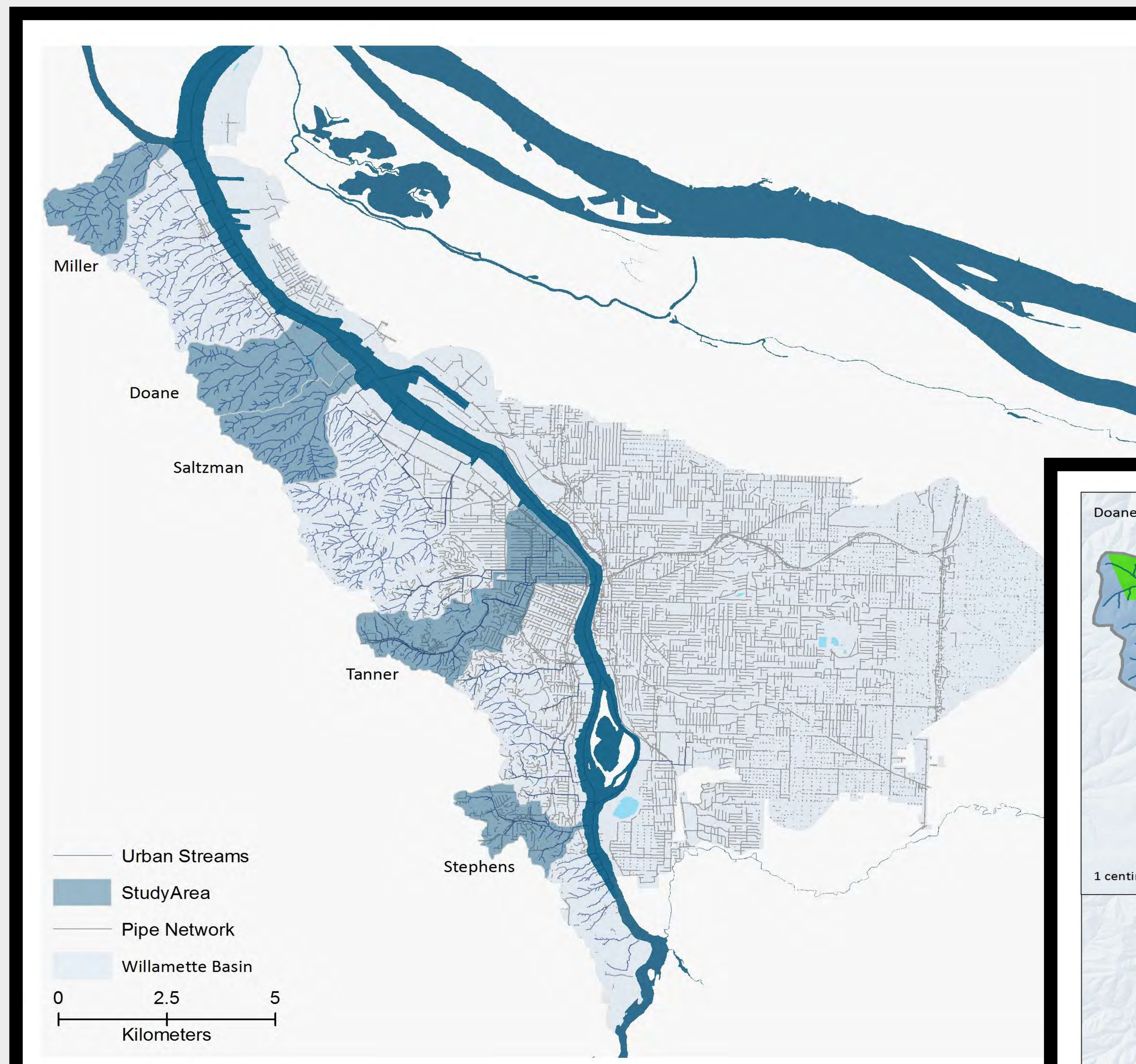




Percent of impervious area to percent of piped stream across 18 subwatersheds in the Willamette Basin

While urban stream density analysis reveals that open channels are significantly clustered in Forest Park and along the west side corridor, stormwater pipes and impervious area density are highest in the westside urban core and extend approximately five kilometers east of the Willamette River. The patterns indicate that stream burial is highest in the commercial, industrial, and high density residential areas, and lowest in environmental protection zones and open spaces. Stream and pipe network density were derived by running kernel density analysis on pipe vertices and stream segment points. The results indicate an inverse relationship between open channels and stormwater pipe networks.

Portland's urban stream desert can be determined by identifying the loss of open channels in heavily developed areas once identified as places with hydrologic connectivity. This study delineates Portland's urban stream desert using GIS analysis of urban stream and stormwater pipe networks, impervious surface area, and zoning designations. Getis-Ord Gi* Hot Spot analysis was run with storm pipe vertices and impervious area to identify areas of statistically significant clustering within the Willamette Basin. The results of the clustering were merged to identify overlapping clustering of impervious area and pipe networks. The areas with high clustering of both attributes were then identified as the delineated urban stream desert.

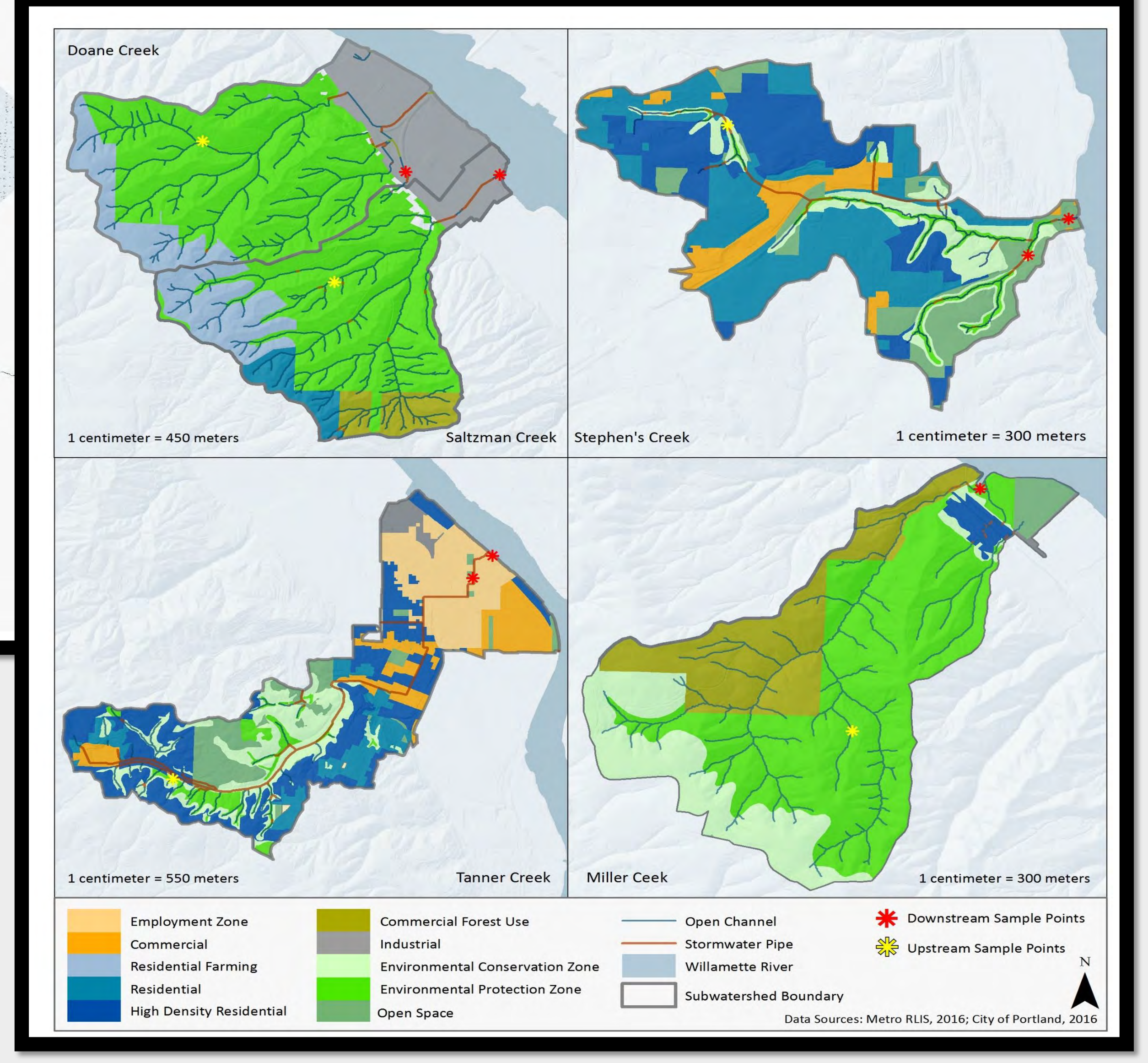


The City of Portland Bureau of Environmental Services collects water quality and habitat data by subwatershed in multiple capacities. The data represented below was collected in monthly grab samples between 2008 and 2016. Upstream samples were taken from open channels in environmental protection or conservation areas. Downstream samples were taken from pipes, culverts, or outfalls. For each stream in the study, the downstream reaches are considered to be heavily altered by development. The figures below indicate average upstream and downstream values and the difference between them.

Tanner Creek is piped from its headwaters in a conservation zone to its confluence at milepost 11 in the Willamette River. Tanner Creek runs in pipes directly under Portland's urban core and has cultural importance as one of the city's most well-known lost streams. The majority of the pipe is fed from the remaining intermittent headwater streams of Tanner Creek and the adjacent stream Johnson Creek. Runoff from roads enters the pipe after being filtered through a series of swales before disappearing underground for its conveyance route to the river.

Doane, Miller, and Saltzman Creeks each originate in Portland's West Hills and flow in open channels through the commercial forest area and environmental protection zones in Forest Park before they are piped under major industrial areas. Saltzman and Doane Creeks flow entirely in open channels until reaching Highway 30, a main arterial, where they are forced through culverts and open concrete channels under the railroads and major arterials. Saltzman Creek reappears in its final 300 feet where it meets the Willamette River. Miller Creek, with the highest percent of open channel, flows through a culvert only under Highway 30 and the railroads.

While the majority of Stephens Creek flows in an open channel, it has been heavily altered by residential land use and a very moderate amount of open space and environmental zones. There are several major corridors that intersect and follow the creek before it reaches the Willamette River. Stephens Creek is characterized as highly urbanized and will be used as a comparison for the other streams in the Willamette watershed.



The stream degradation associated with urbanization includes increased flashiness, reduced biodiversity, altered geomorphology, and increased nutrient loading (Walsh et al., 2016). With the increase of impervious area, stormwater moves more quickly into both open channels and stormwater drains. Not only does this contribute to a flashy hydrograph, but it also provides a conduit for pollutants to go directly into the streams and rivers without the opportunity to filter through vegetation and soil (Jacobson, 2011; Walsh et al, 2005; Hatt et al, 2004). Additionally, the increase of impervious area and loss of permeable soils and wetlands reduces groundwater recharge, negatively impacting base flow (Hale et al., 2015; Walsh et al. 2012). Habitat loss associated with altered stream channels have contributed to increase of invasive species and limited fish passage (Cooper et al, 2013).

While stream degradation is widely known to be associated with urbanization, measuring the impact of urbanization has proven to be challenging due to the variation across urban areas and the difficulty in referencing a target condition. For instance, there are several streams just outside the Portland area that are not impacted by urbanization, however they are experiencing degradation associated with rural agricultural runoff. By analyzing water quality parameters between upstream and downstream sample points of several urban streams, impacts of urban development can be compared across a variety of land uses.

Water Quality Comparison Method

The water quality conditions compared in the streams include, temperature, pH, Dissolved Oxygen (DO), conductivity, and Total Suspended Solids (TSS). Each of these parameters are physical and chemical indicators of stream health and can be useful in identifying areas with restoration potential. The water quality data was collected by the City of Portland Bureau of Environmental Services from 2008 to 2016. The sample points include upstream and downstream monitoring locations. The results were aggregated by upstream reaches and downstream reaches of each stream. The mean values were compared to detect differences in water quality between upstream and downstream locations. The comparison results were used to determine the degree to which land use and burial impact overall stream health.

Discussion:

Stream function and health are heavily impacted by the change in drainage patterns in urban catchments. While natural streams retain water and function in a way that allows the absorption and filtration of nutrients, urban drainage networks convey water and pollutants directly into receiving streams (Walsh et al; 2016). The upstream and downstream comparison results support the argument that piping streams, confounded by urban development, diminishes stream health and functionality. Tanner and Saltzman and Miller Creeks (55% piped, 33% piped and 27% piped, respectively) show significant differences in three to four out of the five water quality parameters between the upstream and downstream sites. Land use patterns in each of these subwatersheds are the most varied, ranging from conservation zones to commercial and industrial areas. Stephens Creek, at 30% piped, is perhaps the most degraded of the streams in the study and showed very little difference between upstream and downstream sites. It's possible that this is due to the relatively small variation of land use patterns in the subwatershed; lending itself to more consistent nutrient loading at all points of the stream.

Stream	DO	Conductivity	TSS	pH	Temp
Tanner	0.086268	0.038496	0.236013	0.069683	0.000123
Stephens	0.301463	0.123112	0.652913	0.048664	0.602251
Miller	0.312769	1.08E-07	0.089375	0.042619	0.975339
Saltzman	0.063948	0.054813	0.089841	0.586796	0.013808
Doane	0.556642	0.302348	0.694111	0.145567	0.065258

P-Value results for T-Tests comparing upstream and downstream sites by stream

Limitations to these results include the difference in data points and number of observations. With the exception of Doane Creek, there were many more observations for the downstream points than the upstream points. Given the nature of observational data and the confounding factors of urban development and stream health, it is difficult to determine whether increased stream burial is a direct cause of degraded water quality, or whether it works in tandem with other factors that contribute to degraded water quality (such as land use patterns, existence of major roads, etc). Patterns in urban development and variation of land use are often synonymous with both stream burial and degradation indicating that a more controlled data collection design would be necessary to further assess the impacts of stream burial on water quality.

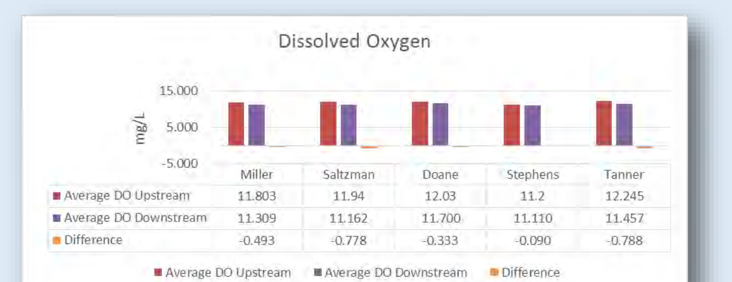
The Oregon Administrative Rules (OAR 340-041-0016(3)) mandates that Dissolved Oxygen in waters supporting cold water aquatic life may not fall below 8.0 mg/L as a 30-day mean minimum, 6.5 mg/L as a seven-day minimum mean, and may not fall below 6.0 as an absolute minimum (DEQ, 2004). While each of the streams are within the acceptable range, every stream in the study has a decrease in DO between the upstream and downstream reaches with an average decrease of .5 mg/L among all the streams. In urban streams, decreased dissolved oxygen is caused by reduction in stream riffle and stream bank complexity; a possible consequence of piping.

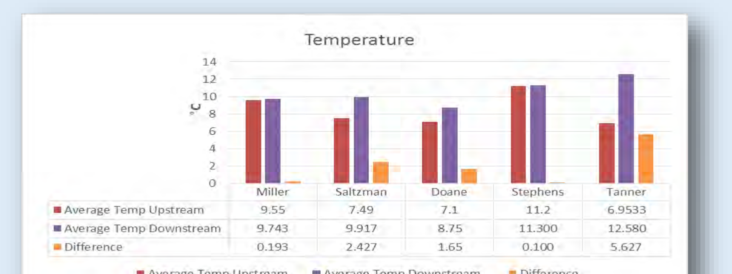
The Oregon Department of Environmental Quality recommends that stream temperature does not exceed 18ºC. While none of the streams in the study reached the maximum allowable temperature, a general trend of temperature increase can be noted between upstream and downstream locations. Tanner Creek had the largest average temperature increase from the headwaters to the outfall with difference of 5.6ºC. Stephens Creek had the smallest change in temperature which could be explained by the homogeneity of land use (70% residential development) throughout the subwatershed. Additional analysis of the downstream temperature data revealed that while Tanner Creek was an average of 6ºC lower than the main stem Willamette River in the hottest months, it was still an average of 4ºC warmer than comparable neighboring streams. Changes in temperature not only impact the geographic distribution of cold water species, but also have cumulative watershed impacts which include the determination of chemical and biological processes (Mayer, T, 2012; McCullough et al, 2009). Further research is necessary to determine whether or not daylighting Tanner Creek in strategic areas would reduce the temperature on the hottest days and provide a refuge for cold water habitat.

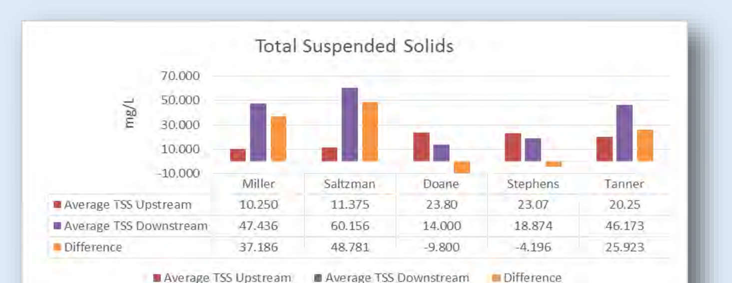
Total Suspended Solids can be used a surrogate parameter to water quality as an indicator of metals and organic compounds which are absorbed and transported by TSS (Wilbur&Clark, 2001). Elevated concentrations can have a negative effect on aquatic life. While water quality criteria has not been established for TSS, its positive correlation with other stormwater pollutants is widely known (Maybeck et al, 2002; Gray et all, 2000). The Portland Stormwater Management manual acknowledges the that increases TSS levels are related to urban development and requires a 70% removal of TSS from 90% of the average annual runoff from new development. While the USEPA has yet to set guidelines on TSS levels, The Ministry of Environments Land and Park, British Columbia has set a measurement guideline of 25 mg/L for aquatic life (Singleton, 2001). Tanner, Saltzman and Miller Creeks each show very large increases in TSS with differences between upstream and downstream sites, ranging from 26-37 mg/L. Doane and Stephens Creeks show a reduction in TSS between the upstream and downstream sample sites. While further research is required to understand the relationship between land use and TSS, the parameter is still a viable indicator of subwatershed health and can be considered in watershed management decision making.

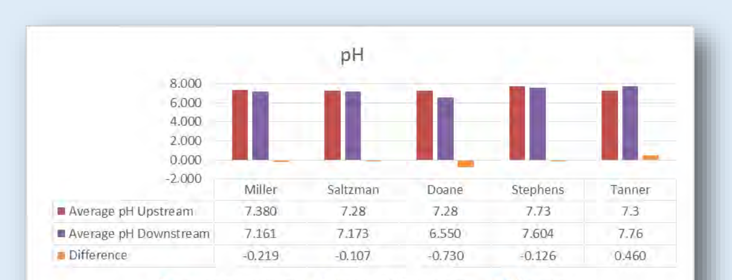
Conductivity is the measurement of water to carry an electrical current and it can be used to determine mineralization and dissolved solids in water. While there are no regulatory levels of conductivity, it can be a good indicator of pollutants that may exists in the water including salinity and dissolved solids. Abrupt changes in conductivity can effect aquatic life that have adapted to certain ranges of specific conductivity in their habitat. Tanner and Miller Creeks had the largest mean difference in conductivity levels between upstream and downstream sites indicating that cold water migratory habitat would potentially be confined to specific areas in the streams given that pipes and culverts were passable.

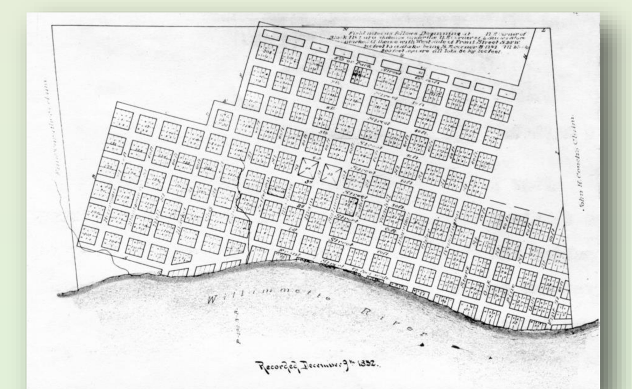
The Oregon Administrative Rules (OAR 340-041-0345(b)) states that pH values may not fall outside the range of 6.5 to 8.5 for all waters in the Willamette Basin. No Creeks in the study exceed the maximum or fall below the minimum; Tanner Creek was the only stream to show an increase in value











Open channel in the Jefferson-Mill Subwatershed 1852. Source: The City of Portland.

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Data	Type	Source
Water Quality	Temperature, pH, Dissolved Oxygen (DO), Specific Conductivity, and Total Suspended Solids (TSS)	Bureau of Environmental Services, 2008 – 2010; Portland Area Watershed Monitoring and Assessment Program, 2008 – 2016.
Historic Streams	Digital Elevation Model. Cadastral Surveys	CSAR, 2016; City of Portland Archives; The Oregonian, 1850 – 1860. Oregon Historical Society
Shapefiles	Stream Networks, Stormwater and Sewer, Land use: Impervious area, Environmental Overlay, Development	BES, 2016; Portland Maps, 2016; RLIS, 2016; CSAR 2016

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