Tools for evaluating pollutant areas of influence within streams and marine waters of South Puget Sound

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Abstract

The Department of Ecology uses a variety of approaches, ranging from simple, field-based analyses to complicated modeling strategies, to understand areas influenced by particular pollutant sources. These tools include dissolved tracers, drogues, and hydrodynamic models. For example, we evaluate travel time using dissolved tracers within freshwater systems, such as the Deschutes River and Woodland Creek, to understand how much bacterial die-off may occur following release from a specific source area. In related marine studies, surface drogues indicate the direction and speed at which water travels within water bodies such as the Nisqually Reach and Henderson Inlet. The results can be used to map areas that influence water quality in shellfish beds. Nearshore drogue releases also identify shoreline areas of influence. Finally, hydrodynamic models can simulate tracer releases on larger time or spatial scales. We applied a three-dimensional hydrodynamic model of South Puget Sound to understand the likelihood that wastewater outfall effluent influences shellfish beds within the Nisqually Reach. Each of these studies provided highly valuable information.

Introduction

Will a pollutant source at location X affect a beneficial use at location Y? The question arises in a number of studies of impaired water bodies in South Puget Sound and elsewhere. The Department of Ecology uses approaches ranging from simple, field-based analyses to more complex modeling strategies to understand areas influenced by particular pollutant sources. The data provide important insights to the relative importance of various potential sources of contamination in addition to calibration data with which to compare output from water quality models. These tools include dissolved tracers, drogues, and tracer simulations using hydrodynamic models.

Figure 1 presents the locations of tracer studies from several ongoing Department of Ecology projects. No single approach will work in all water bodies under all hydrologic and hydrodynamic conditions, but these examples were selected to offer simple approaches that could be adapted to a wide range of freshwater and marine applications. This paper does not present an exhaustive list of tracer applications (Kilpatrick and Wilson 1989).

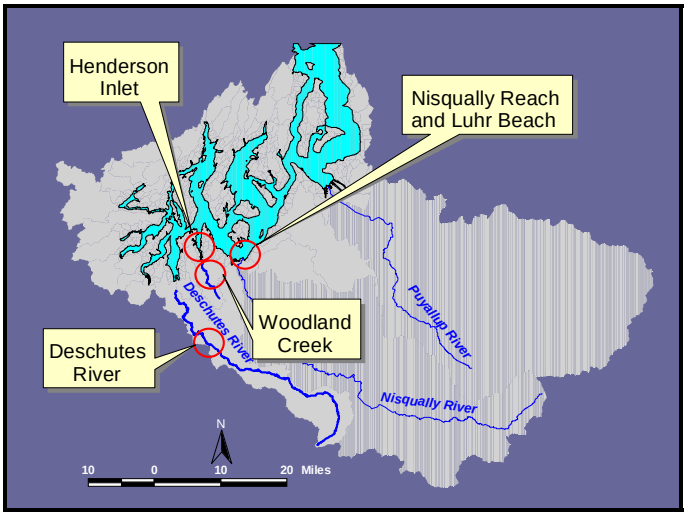

Figure 1. Travel time study locations within the South Puget Sound watershed.

Woodland Creek Salt Pulse

Fecal coliform bacteria and temperature levels do not meet the Washington State water quality standards in Woodland Creek, a stream that discharges to Henderson Inlet near Lacey. The Department of Ecology began studying sources of the impairments in 2002. The study approach included travel time studies in the monitoring plans to understand the potential areas of influence of upstream bacteria sources as well as the potential accumulation of heat in the system (Zalewsky 2002; Sargeant et al. 2003).

We used a pulse release of dissolved salt solution for the tracer study. Low flows in the system warranted very low volumes of salt solution, and the shallow water depths precluded the use of drogues. We minimized the amount of salt added to the system to avoid toxicity to freshwater life due to salinity. The water quality standards apply freshwater criteria to those waters where 95% of the daily depth-averaged salinity is <1‰ (part per thousand). We targeted a maximum instantaneous salinity of <0.5‰, which is well below both the acute and chronic criteria for chloride (860 and 230 mg/L, respectively). We prepared a series of dilutions to estimate conductivity as a function of salinity. From Figure 2, we selected a maximum conductivity of 1,000 uS/cm (1,000 umhos) to maintain a salinity of <0.5‰.

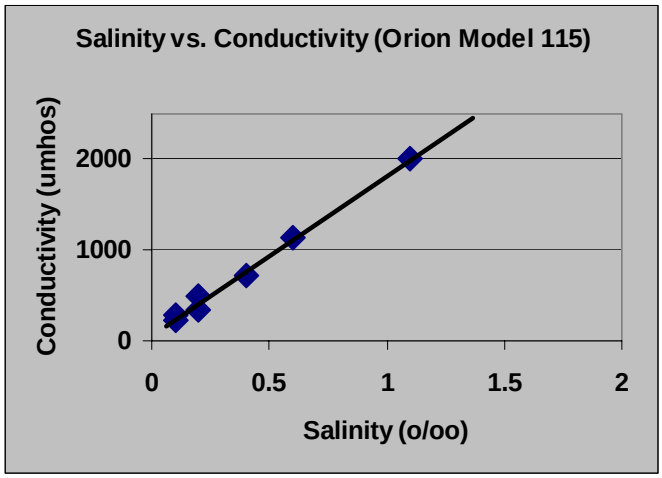

Figure 2. Relationship between salinity and conductivity used to establish maximum values for freshwater travel time studies using salt tracers.

The salt tracer study was conducted at low-flow conditions, when temperature was expected to be highest and velocities the lowest, on August 22, 2003. Discharge was 13 cfs (0.37 cms) within the monitored reach. We released approximately 500 mL of saturated salt solution and recorded conductivity at 30-second to 2-minute intervals at three stations downstream (100 ft, 2,400 ft, and 3,700 ft, or 30, 730, and 1,130 m). Figure 3 presents the conductivity time series at all three locations. Background conductivity was about 120 uS/cm. Conductivity peaked at 180 uS/cm immediately downstream of the release, well below the conservative target. The salt tracer was evident even after 90 minutes as a peak of 130 uS/cm.

Based on the time each peak passed the two downstream stations, the reaches had velocities of 0.75 and 0.55 ft/s (0.23 and 0.17 m/s), respectively. In comparison, the flow measurement at the middle station on the day of the survey indicated an average velocity of 0.75 ft/s (0.23 m/s) for the station velocity measurement. Therefore, water in the lower reach traveled more slowly than the station velocity, although the upper reach tracer velocity matched the station value. The tracer travel time accounts for velocity variations resulting from the pool-riffle structure and other channel complexity present in Woodland Creek that cannot be captured by an instantaneous discharge measurement. Extrapolating to the entire system, bacteria can be transported from the headwaters to Henderson Inlet in about 12 hours. Therefore, relatively little die-off is expected to occur, and bacteria sources throughout the Woodland Creek watershed likely affect levels in Henderson Inlet.

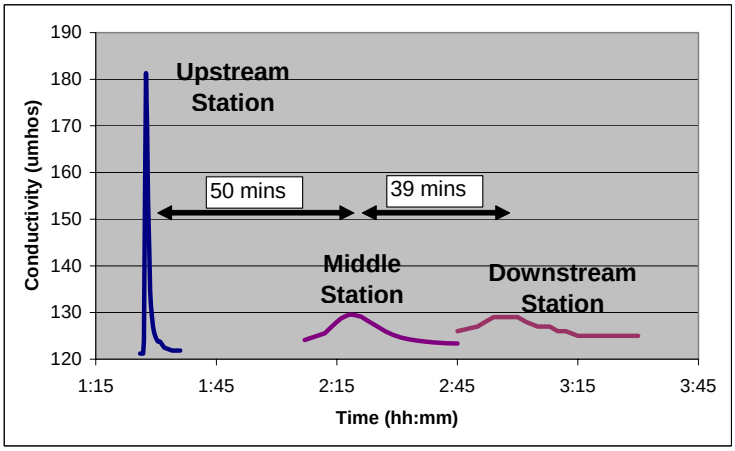

Figure 3. Conductivity recorded at three stations downstream of the salt solution release to Woodland Creek.

Deschutes River Rhodamine Dye Releases

The Deschutes River does not meet the water quality standards for temperature. To understand the sources of the impairment, we are developing a one-dimensional model of the Deschutes River to simulate the hottest period of the year, which occurs under low-flow conditions. Understanding how water moves through the system is fundamental to properly modeling the Deschutes River. As described in Roberts et al. (2004), we included a travel time study in the monitoring plan to provide calibration data for the one-dimensional model.

We chose rhodamine dye as the tracer because it can be detected at levels over several orders of magnitude. The long river reaches precluded the use of salt tracers and the sinuosity of the river precluded the use of drogues. Rhodamine dye is not harmful at concentrations below 10 ug/L when the receiving water body nitrite levels are below 50 ug/L (Kilpatrick and Wilson 1989). Beginning with the most downstream reach and working upstream, we released 250 mL of 20% rhodamine WT dye at three locations and recorded dye concentrations using grab samples at several downstream locations during the period August 2 through 6, 2004. Sample concentrations were determined using a calibrated fluorometer. During the study, discharge at the Rainier gage ranged from 27 to 30 cfs (0.76 to 0.85 cms). We used a series of grab samples to identify the time the peak concentration passed each site. Initial travel times were estimated using previous station velocity measurements and techniques described in Kilpatrick and Wilson (1989). Figure 4 presents an example concentration plot where the dye cloud was well characterized by the grab samples. However, at some stations, the plot was truncated on either the rising limb or falling limb where actual travel time was much different than estimated. Grab samples were used to increase the number of stations that could be monitored, since only one fluorometer was available. Using multiple moored fluorometers *in situ* would avoid truncating the dye curve if more were available.

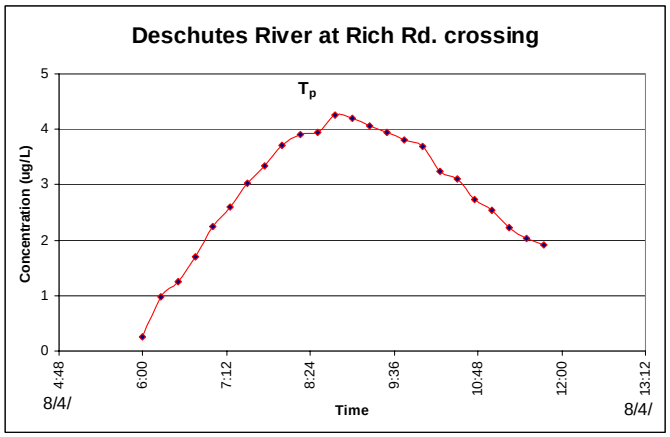

Figure 4. Rhodamine dye concentration time series at river mile 9.6 (15 km) during the Deschutes River travel time study.

Figure 5 presents the cumulative travel time and incremental velocity in the Deschutes River, from the most upstream site at river mile 28.6 (46 km) to river mile 0.5 (0.8 km) in Olympia. The results indicate a surprisingly constant average velocity throughout nearly 30 miles of river length. At low flows, water travels the 30-mile length of river studied in three days. These results will be used to calibrate the temperature model.

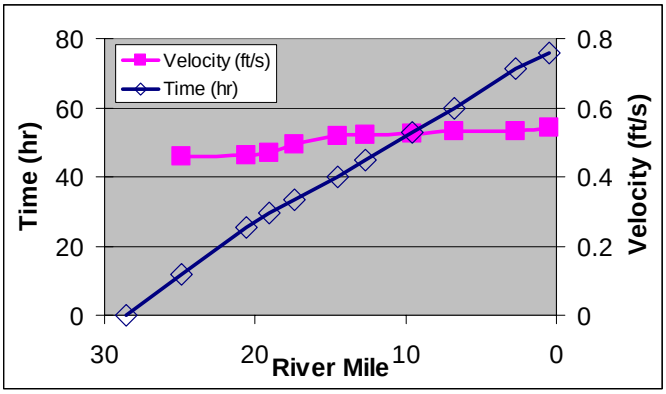

Figure 5. Cumulative travel time and tracer-based velocity results for the Deschutes River during low-flow conditions (August 2004).

Henderson Inlet Drogue Study

Henderson Inlet does not meet the water quality standards for fecal coliform bacteria. Sargeant et al. (2003) summarize the monitoring and modeling approach, which included drogue studies to determine the areas of influence of several creeks discharging to the inlet. The Department of Health has prohibited shellfish harvest from the southern part of the inlet, although shellfish harvest is conditionally approved in the central inlet and approved in the northern inlet (Figure 6).

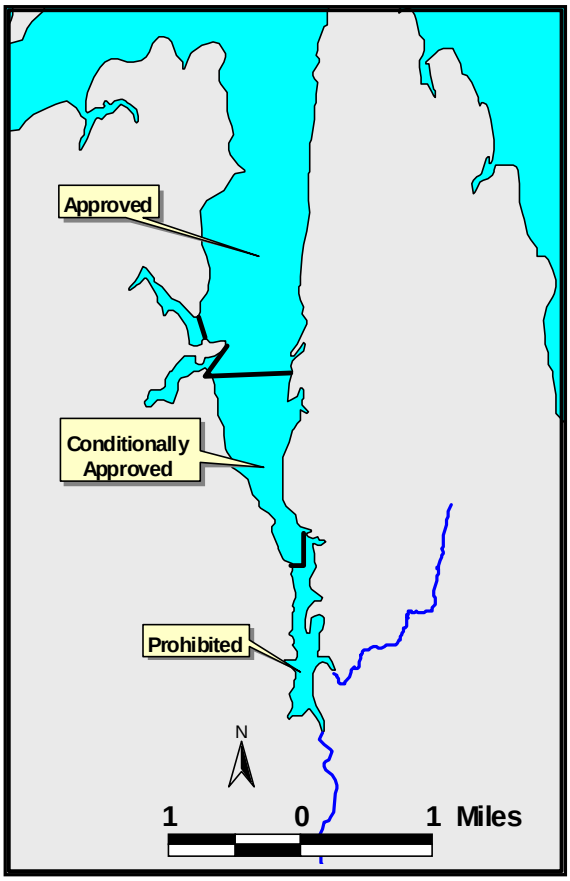

Figure 6. Henderson Inlet shellfish zones determined by Department of Health.

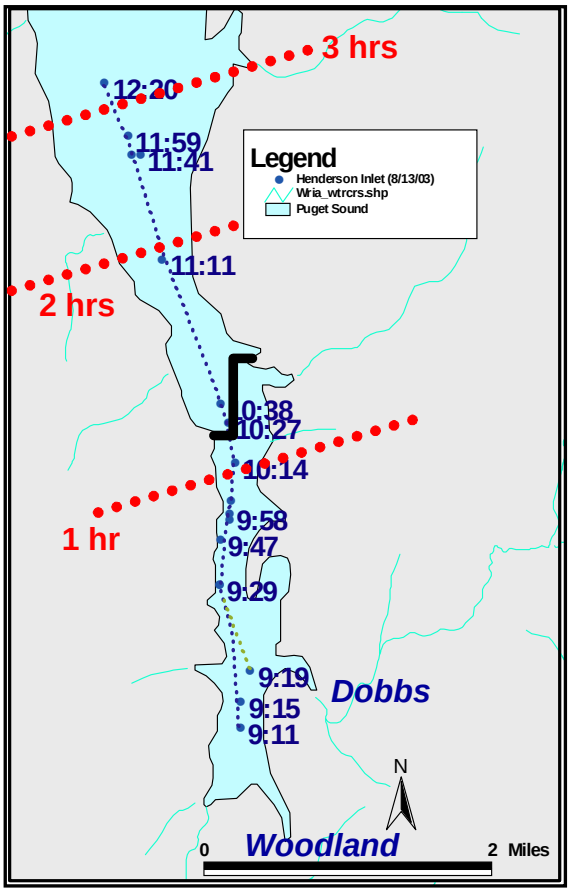

Figure 7. Southern Henderson Inlet travel time during moderately strong ebbing tides (August 13, 2003).

Drogues were selected to track the surface layer where freshwater influences are likely. We evaluated multiple creeks during ebbing tides on February 19, 2003, and August 13, 2003. We alternated releases of 50 oranges and 50 grapefruits to distinguish trajectories from Woodland Creek and Dobbs Creek. After the drogues were released, field personnel used a boat to occupy the center of the drogue cloud and record time and position using a handheld gps. Figure 7 presents the results of the August 2003 event. Drogues from Woodland and Dobbs creeks reached the northern extent of the prohibited zone within 2 to 3 hours; at these velocities, Woodland Creek and Dobbs Creek water can reach the southern extent of the approved shellfish zone at Woodard Bay in 4 to 5 hours, or within a single tidal cycle. The drogues traveled 10,600 ft (3,200 m) in 190 minutes for a cumulative velocity of 0.9 ft/s (0.3 m/s). Results were similar for the February 2003 ebbing-tide release, when drogues traveled 7,800 ft (2,400 m) in 160 minutes for a velocity of 0.8 ft/s (0.25 m/s).

Travel times through Woodard and Chapman Bays were evaluated using drogues released at the mouths of Woodard Creek and Libby Creek during an ebbing tide on April 22, 2003. Drogues traveled 4,000 ft (1,200 m) in 90 minutes in Woodard Bay for a net velocity of 0.7 ft/s (0.2 m/s), while velocities were lower in Chapman Bay at 0.5 ft/s (0.1

m/s) for the same tidal conditions. Water from Woodard or Libby creeks passes through the bays to reach the approved shellfish area in 2 to 2.5 hours; therefore, these streams likely influence central Henderson Inlet water quality.

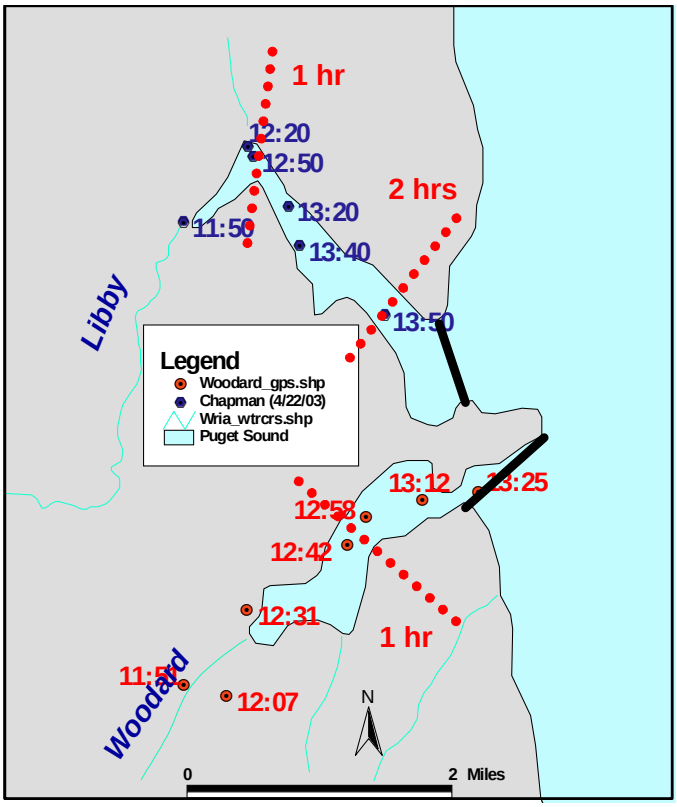

Figure 8. Woodard and Chapman Bay travel time during moderately strong ebbing tides (April 22, 2003).

Luhr Beach Multiple Drogue Releases

While the Nisqually Reach meets water quality standards for bacteria, McAllister Creek, at the western extent of the Nisqually Reach, does not. Department of Health, Thurston County, and Ecology were concerned that the poor water quality in McAllister Creek could influence water quality in the shellfish beds northwest of Luhr Beach, in addition to those along the Nisqually Flats. Thurston County Environmental Health staff also have noted a persistent, highly concentrated source in the vicinity of Luhr Beach for several years. As described in Sargeant et al. (2003), we conducted a drogue study during an ebbing tide on September 25, 2003, to understand areas of influence around Luhr Beach. We used the same methods described above for Henderson Inlet, alternating releases of oranges and grapefruits.

As shown in Figure 9, drogues released near the Luhr Beach boat launch traveled the fastest (1.2 ft/s or 0.35 m/s) and the farthest (9,500 ft or 2,900 m) from the release point in an arc trending to the northeast. Northwestern or clockwise trajectories were noted for drogues released from Meridian and DeWolf Bight. Drogues released at Butterball Cove had low southeastern velocities (0.1 ft/s or 0.03 m/s). Drogues released near Tolmie State Park traveled counter-clockwise and relatively slowly.

The findings suggest that during ebbing tides, conditions in the McAllister estuary and near Luhr Beach appear to influence water quality to the north and east of Luhr Beach only, and not to the northwest. Local conditions and shoreline areas between Luhr Beach and Tolmie State Park appear to be the primary influence in relatively small circulation cells. The patterns are consistent with the net shore drift cells presented in Schwartz and Hatfield (1982).

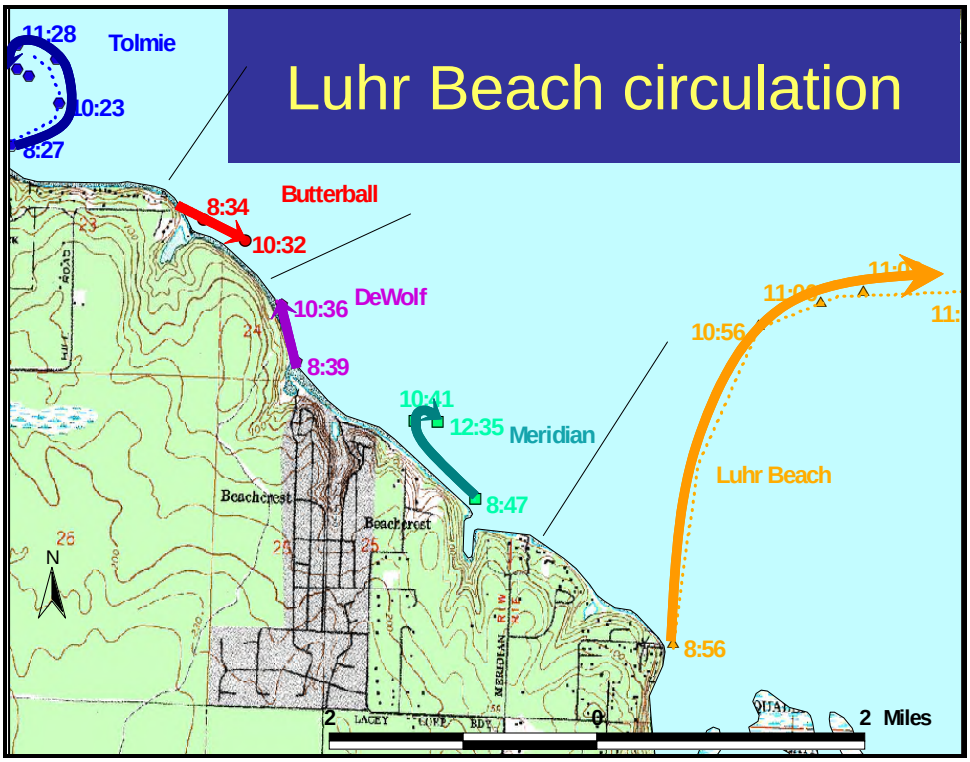

Figure 9. Luhr Beach drogue trajectories during a moderately strong ebbing tide on September 25, 2003.

Nisqually Reach 3-D Model Simulation

The water quality study of the Nisqually Reach also evaluated the effect of a point source discharge on the shellfish beds (Sargeant et al. 2003). The Fort Lewis wastewater treatment plant discharges treated effluent 2.5 miles (4 km) to the northeast of the Nisqually River delta. Some raised concerns that the effluent was contributing to rising bacteria levels found at the Department of Health monitoring stations in the classified shellfish areas. The Department of Ecology had previously developed a 3-dimensional hydrodynamic and water quality model of South Puget Sound (Albertson et al. 2002) using the Environmental Fluid Dynamics Code (EFDC); we proposed to use the South Puget Sound EFDC model to understand the area of influence of the wastewater treatment plant.

To evaluate the worst-case scenario, we simulated a conservative tracer (no die-off) released continuously from the outfall at the highest flow rate recorded at the plant since 2001 and at the maximum fecal coliform bacteria concentration permitted by EPA (permit no. WA0021954). The model simulated an 18-month period, but Figure 10 presents results for July 1, 2004, marked by a very fast flooding tide. An independent drogue study conducted at that time found surface waters traveled 4,600 ft (1,400 m) in 220 minutes for an overall velocity of 0.3 ft/s (0.1 m/s) near the outfall, but speeds increased for drogues released near the mouth of Sequalitchew Creek, located 1 mile (1.6 km) to the northeast of the Nisqually Flats, to 1.2 ft/s (0.4 m/s). The drogue trajectories confirmed those predicted by the EFDC model. While the drogue trajectories and model runs indicate the plant effluent can reach the Nisqually Flats, the model runs indicate that bacteria concentrations peak at 0.0004 organisms per 100 mL, even without die-off. Therefore, the Fort Lewis wastewater treatment plant, operating under the current flow regime and within the permit limits, is not expected to contribute to elevated bacteria levels found periodically at the DOH monitoring locations within the Nisqually Flats.

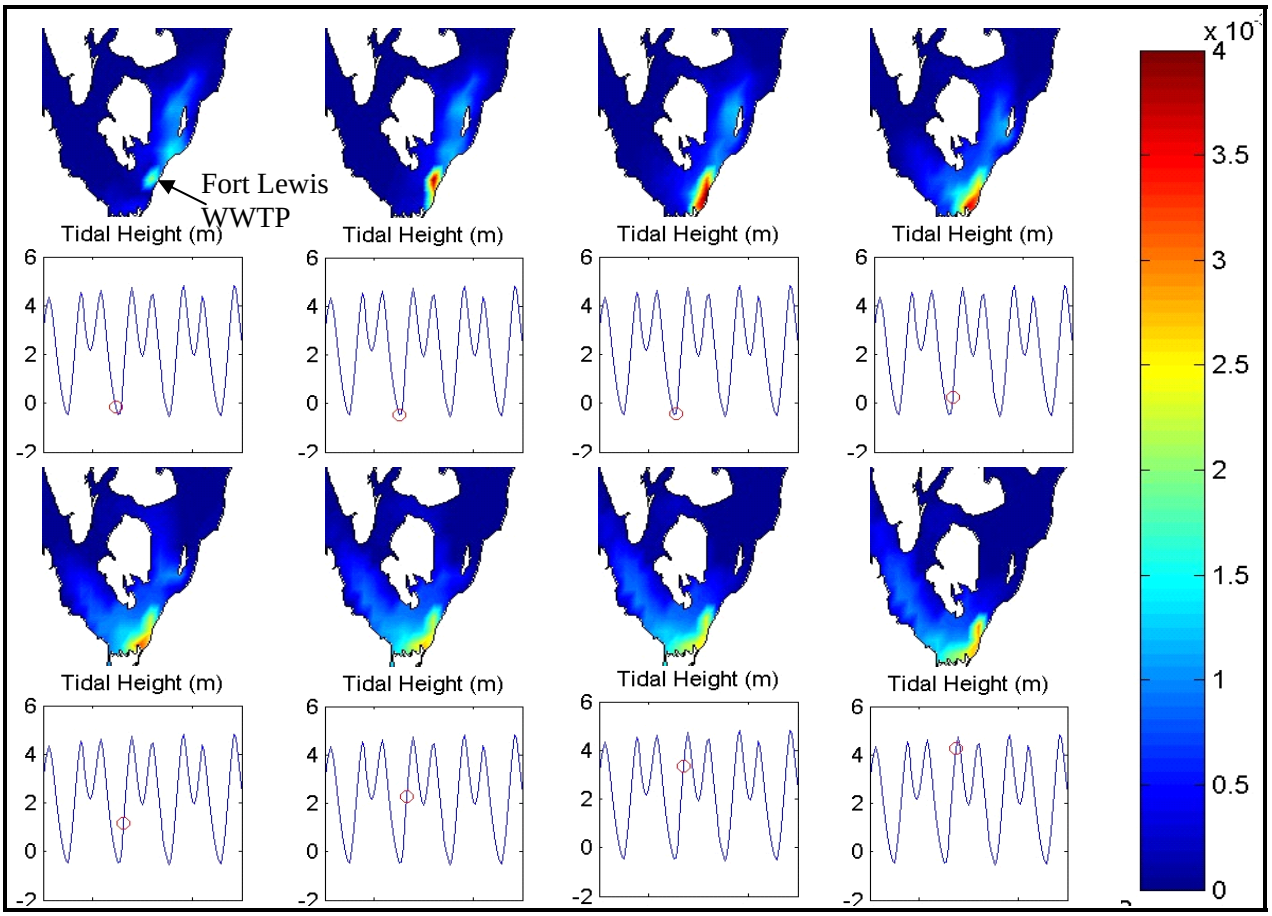

Figure 10. Simulated release of fecal coliform bacteria from the Fort Lewis wastewater treatment plant at Tatsolo Point (red indicates concentrations of 0.0004 per 100 mL) for July 1, 2004.

Discussion

The Department of Ecology uses dissolved tracers and drogues in a variety of studies to address the question: Will water near a potential pollutant source reach an area with a particular beneficial use? With the use of models, we also are able to quantify the likely concentrations exhibited near the beneficial use of interest. Each of the examples presented in this paper was designed to address specific questions. Implicit in the design is the selection of critical conditions during which to conduct the studies.

In the Deschutes River, the results will be used to calibrate a model of the river during critical conditions. For temperature, critical conditions generally occur when discharge is lowest and solar radiation is highest during the summer. Less water depth is available to disperse the heat, and more heat is absorbed as the residence time increases. Therefore, the slowest velocities are most critical.

For the Woodland Creek system, water temperature is of concern, but bacteria transport also is an issue. Low-flow velocities indicate the longest residence time available for bacterial load attenuation. The relatively quick transport during low-flow conditions confirms that bacteria sources located close to Woodland Creek anywhere along its length likely affect Henderson Inlet quickly and with little attenuation. A similar study could have been conducted at higher flows representative of wet-weather conditions, but we had already learned that transport is fast.

Once that water reaches southern Henderson Inlet, the drogue studies confirm that Woodland Creek and Dobbs Creek water travels quickly through the southern inlet on an ebbing tide. We selected moderately fast ebbing tides during which to conduct the study. The narrow shape enhances transport through the inlet and contributes to the connectivity of the inlet and its watershed.

Drogue studies indicate that during ebbing tides, water from McAllister Creek and its estuary travel to the northeast and do not affect water quality to the northwest of Luhr Beach. In fact, multiple drogue releases indicate a series of small circulation cells, where local shoreline sources likely control the water quality.

To evaluate the effect of the Fort Lewis wastewater treatment plant on shellfish beds in the Nisqually Reach, we needed to quantify the concentrations expected after we found the water mass trajectory did reach the beds during flooding tides. We were able to apply a 3-dimensional model of South Puget Sound developed for an earlier project to quantify both plume direction and concentration magnitude. Using a series of worst-case conservative assumptions for the plant, we established that the plant does not contribute to bacteria levels within the Nisqually Reach shellfish beds, even during relatively fast transport during flood tides.

The tracer studies provide invaluable information on transport from potential pollutant sources to waters with a particular beneficial use. The selection of the type of tracer, dissolved or drogue, varied with the environment being studied. When using dissolved tracers, such as salt or rhodamine dye, care must be taken to avoid toxicity to the aquatic community. Drogues, including biodegradable oranges and grapefruits, should be retrieved at the completion of the study. When used properly, tracers greatly enhance system understanding, which improves our ability to identify and mitigate pollutant sources.

Acknowledgements

Many of the drogue studies near Luhr Beach and the Nisqually Reach were conducted in cooperation with the Department of Health and Thurston County Environmental Health. Special thanks to Frank Meriwether and Sue Davis.

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