NHC Ref. No. 2001396

December 22, 2017

Kitsap County Public Works, Surface and Stormwater Management Program
8600 SW Imperial Way
Bremerton, WA 98312

Attention: **Chris May**
Surface and Stormwater Management Program Director

Re: **Hydrologic and hydraulic analysis of Duncan Creek flooding, culvert replacement, and flow control options**

1 INTRODUCTION

Duncan Creek enters Puget Sound approximately 0.1 miles south of the Manchester village in unincorporated Kitsap County. The creek drains a total area of approximately 280 acres that is located to the west and south. Single family residential development occupies approximately seventy percent of the basin, concentrated primarily to the west of Alaska Avenue between E. Alder Street on the north and E. Harrison Street on the south, but with additional patches to the east of Alaska Avenue. Forested ravines and the main, forested creek valley make up the remainder of the basin. Duncan Creek crosses under Colchester Drive south of its intersection with Hemlock Street through a 250-ft long, 36-inch diameter pipe system. The pipe system conveys the creek flow eastward through a 125-ft culvert section to a manhole that turns the flow southward for another 125 feet to another manhole that returns the flow to an easterly direction through a short pipe section that daylights to an open channel section that flows for approximately 400-ft before reaching the shore of Puget Sound. For most of this open channel length, the creek is confined between structures and developed hard landscaping on a single parcel that straddles the creek. These structures include a garage, driveway, and shed on the left bank, and a main house and guest house on the right bank. In recent years, there have been numerous complaints of high water and flooding within this parcel.

WDFW maps the Colchester Drive culvert as a complete fish blockage, probably because of its length and the restricted size of the pipe compared to the bankfull width of the creek. In recognition of this blockage as well as the need to retire older components of the pipe system, the County is interested in replacing the system with a WDFW-approved, fish-passable culvert that will conduct Duncan Creek under Colchester Drive. However, given the recent history of flood complaints in the property downstream of Colchester Drive, reducing the incidence of flooding along Duncan Creek downstream of Colchester Drive is also an imperative objective.

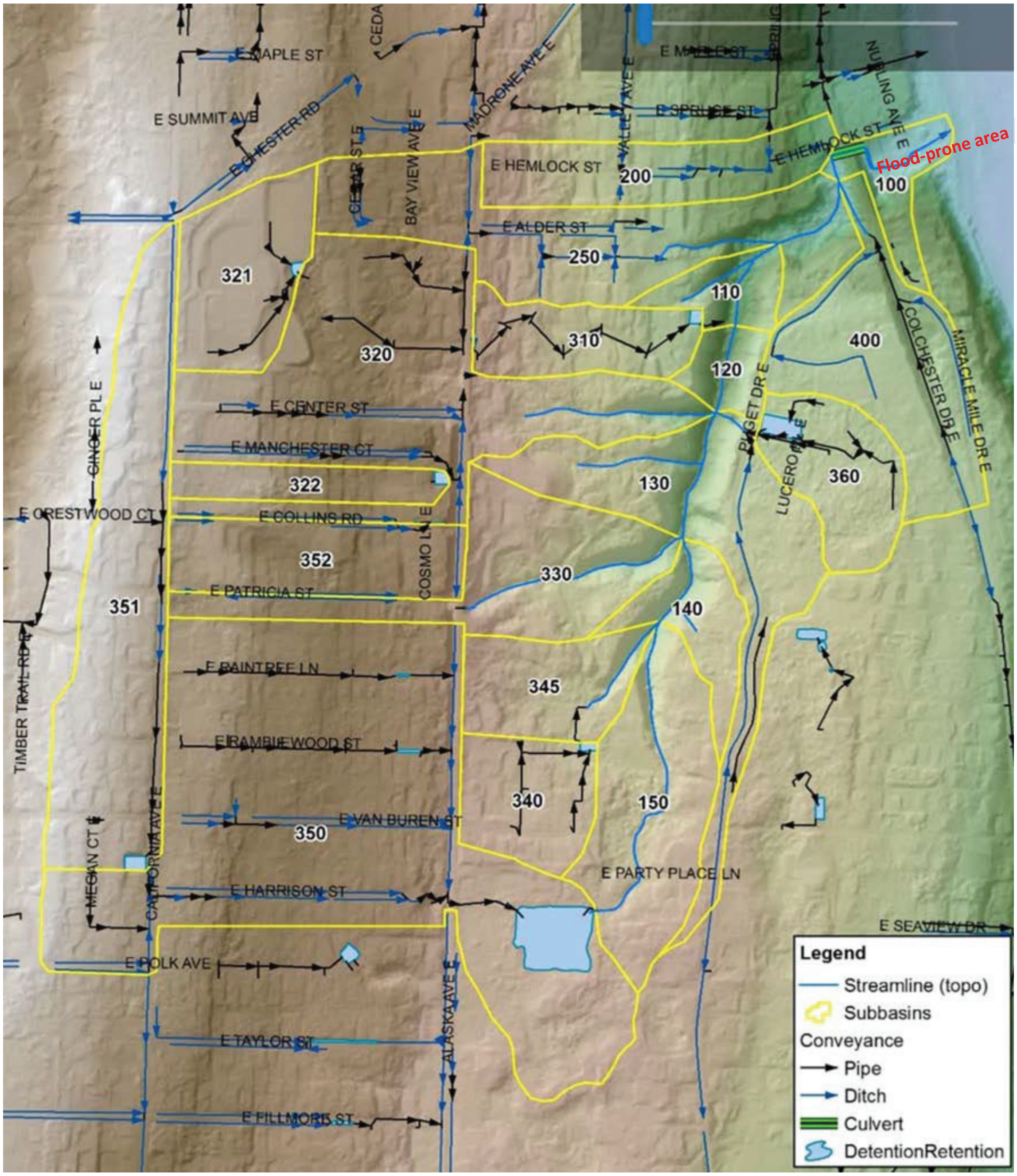

Figure 1: Duncan Creek basin and subbasin delineation

In response to the County's dual objectives of culvert replacement and flood reduction, NHC was engaged to analyze the flooding problem and then develop and evaluate project concepts in terms of their flood reduction, fish passage, aquatic habitat and water quality benefits. This report documents these efforts.

To this end, NHC took the following steps.

1. Performed a basin reconnaissance accompanied by County staff.
2. Developed and qualitatively screened a set of potential projects based on evaluation criteria stated above.
3. Used GIS coverages and analysis, as-built drawings, and hydrometric data to build and calibrate a basin-wide hydrologic model for purposes of quantitative assessment of short-listed projects.
4. Developed and calibrated a first-cut hydraulic model of the flood-prone reach based on field reconnaissance and the County's 2013 survey basemap of the creek and adjacent properties. This model was used in tandem with the hydrologic model to evaluate flood frequency under both existing and alternative future conditions.
5. Worked with County staff to develop and evaluate a preferred alternative incorporating peak flow reduction coupled with fish passage.

2 BASIN RECONNAISSANCE

On March 15, 2017 NHC staff members met Mauro Heine at the Colchester Drive culvert and proceeded to conduct a basin reconnaissance. This reconnaissance included a constructive visit with Mr. John Read, the owner of buildings and property straddling both sides of the creek in the flood prone area. Mr. Read showed us where water had reach the side of his garage during a storm event a month earlier on February 16. We examined the channel and banks, noting potential restrictions at bridges and more significantly a low rock weir of unknown function. Mr. Read explained that in his estimation flood events were occurring more and more frequently. He has occupied the property for approximately five years. He also noted that the creek goes virtually dry every summer and that he thought the answer to flooding problems as well as increasing summer base flows would be to locate detention storage upstream, possibly behind the Colchester Drive road fill.

Photo 1: 36-inch CMP outfall to flood-prone open channel reach downstream of Colchester Drive.

Photo 2: Duncan Creek in flood-prone reach looking downstream. Water contacted the siding of the garage wall on right on February 16, 2017.

Photo 3: Looking upstream on Duncan Creek within flood-prone open channel reach. Note rock weir control upstream of right bank drain outfall.

Photo 4: Duncan Creek at beach looking upstream.

Photo 5: Duncan Creek discharging to Sound at low tide.

Following our visit with Mr. Read, we made a visual survey of the area of the creek within the Manchester Water District property on the upstream side of the road fill.   There we noted a significant inflow to the right bank of the creek discharging from an outfall on the west side of Colchester Drive where the road fill meets the valley wall. Additionally, a large flexible rubber pipe was visible on the left bank just upstream of the culvert entrance which appeared to be a temporary feature to conduct Hemlock Street storm water non-erosively down the left bank to the creek.

Photo 6: Right bank drainage at intersection of Colchester Drive road fill and Duncan Creek valley wall. Drainage likely initiates from both Colchester Drive to south of Duncan Creek and Puget Drive to southwest.

Photo 7: Water District infrastructure on right bank upstream of Colchester Drive road fill.

After viewing the property, improvements, drainage, and riparian conditions on the upstream side of Colchester Drive, we walked east on Hemlock Street in search of potential alternative stormwater bypass alignments either straight east on Hemlock or jogging north on Nubling Ave to the vicinity of Spruce Street where the County's GIS layer indicated the presence of an 18" storm drain heading west to the beach. A homeowner directed us to the outfall location near the northeast corner of his property. He explained that since the construction of the Stormwater Park, drainage to this outfall had been diverted and past problems with flooding and beach erosion had been curtailed.

The next stop in our reconnaissance was a visit to the Alaska Avenue regional water quality and detention pond that is located near the southern boundary of the basin. The main purpose of this visit was to improve our understanding of the facility which to that point had been based solely on Entranco's 2002 design plan set. Of particular interest was whether an increase in the maximum pond water level could be accommodated without negative impacts on surrounding properties. It appeared that a 1.0-foot increase in pond level would be workable, but might require raising the earth berm to contain the water.

Following the visit to the regional pond, we performed a windshield survey of the neighborhood west of

Alaska Avenue between Harrison Street and Collins Road to assess drainage infrastructure and get a sense of the percentage of houses with roofs connected directly to ditches or storm pipes. We estimated this at approximately 50%.

The final stop for this reconnaissance was in Manchester to see the Stormwater Park and its outfall to the beach as well as to determine whether a connection could be made to the same outfall from Duncan Creek following a pathway northward along Nubling St and continuing along Denniston Lane to Main Street; however, the public right-of-way appears to be discontinuous along this alignment.

3 DUNCAN CREEK CULVERT ALTERNATIVES

Following guidance from the Washington Department of Fish and Wildlife (WDFW) Water Crossing Design Guidelines[1], the design requirements were defined to provide fish passable conditions through the Colchester Drive crossing for native fish. The requirements were based on a stream simulation approach which attempts to reproduce the slope, geometry, and composition of the natural streambed within an oversized culvert. In order to meet a stream simulation design approach, the following parameters must be met.

- Bankfull width[2] less than 15 ft
- Stream slope must be in equilibrium and not more than 1.25 times the upstream channel slope
- Pool – riffle morphology (for stream slopes less than 4%)

3.1 Alternatives Development

The key parameter in determining the culvert size is the bankfull width. Determining bankfull width requires experience in identifying indicators in the field but can be approximated by using cross sections to determine where the bank would be overtopped. A series of cross sections were created from a topographic survey conducted by Kitsap County in 2013. The cross sections were selected a sufficient distance downstream and upstream of the existing culvert to avoid flow expansion or contraction. Typical channel top widths were between 6 and 8 feet.

Because of the uncertainty associated with determining bankfull width in this manner, the anthropogenic factors compounding the geomorphic response, and backwater regularly developing upstream of the culvert against Colchester Drive during flood events, the width estimate was checked

[1] Barnard, R. J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J. P. Klavas, D.C. Ponder, P.D. Smith, and P. D. Powers (2013), **Water Crossings Design Guidelines**, Washington Department of Fish and Wildlife, Olympia, Washington. http://wdfw.wa.gov/hab/ahg/culverts.htm

[2] Bankfull width refers to the width of a natural channel which, once filled with flow, is on the brink of spilling on to the floodplain. For a channel in equilibrium, the discharge that fills the channel to it bankfull width is thought to be the most significant factor in shaping the size and shape of the channel.

against several regime theory relationships relating discharge with channel width. The Nixon[3] and Kellerhals[4] relationships led to the following estimates:

- Nixon: 6.2 feet
- Kellerhals: 6.7 feet

Both of these predictions fall within the measurements taken from the selected cross sections. Based on these estimates, the proposed culvert should be between 10 and 12 feet in diameter based on the design equation for the culvert diameter of 1.2 times the bankfull width plus two feet. The larger diameter (12 feet) is a conservative approach based on a bankfull width of 8 feet. The smaller diameter is associated with a bankfull width of 6 feet and also addresses the observation that any flood reduction measure implemented by the County would tend to reduce the creek bankfull width. The County intends to pursue flood reduction alternatives alongside the culvert replacement; because of this expected decrease in flow, a 10-ft diameter culvert is recommended for the Colchester Drive crossing.

Two culvert alternatives were developed which provided the best potential for achieving fish passage on Duncan Creek based on stream simulation culvert design guidance. The first alternative is a 10-ft diameter culvert installed in an open-cut trench through Colchester Drive. The second alternative is a 10-ft diameter culvert installed by pipe jacking through the Colchester Drive embankment. Both alternatives would be buried approximately 30 – 50% of the culvert diameter. The alternatives are described in detail in the following paragraphs. Cost estimates and figures for both alternatives are included following the report (Table A1 and Figures A1-A3).

3.1.1 10-ft Diameter Culvert – Open Cut Installation

A 10-ft diameter culvert, as shown in Figures A1 and A2, would provide adequate room to develop a stable natural channel beneath Colchester Drive. In order to install the culvert, Colchester Drive would be closed and a trench cut through the embankment down to the proposed culvert flowline. The culvert would be placed at a 2.4 percent slope, roughly equivalent to that of the upstream channel and would include a headwall and wingwalls both upstream and downstream. The total length of the culvert would be approximately 110 linear feet. The open trench excavation would result in the removal and replacement of about 3,600 cubic yards of material and rebuilding the removed portion of Colchester Drive. The estimated cost is just less than $1.1 million.

Benefits:

- Less concern related to unknown composition of road fill and potential obstructions during construction.

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[3] Nixon, M. 1959. "A study of the bankfull discharges of rivers in England and Wales". Proc. Institution of Civil Engineers, London, v.12.

[4] Kellerhals, R. 1967. "Stable channels with gravel-paved beds". Journal of Waterways and Harbors Division, Amer. Soc. of Civ. Engrs, No. WW1, February.

Potential Issues and Concerns:

- Cost and difficulty of open cut installation
- Extended road closure and traffic detours

3.1.2 10-ft Diameter Culvert – Pipe Jacking Installation

In lieu of an open cut installation, a pipe jacking contractor would be selected to push a 10-ft diameter culvert through the Colchester Drive road embankment as shown in Figures A1 and A3. The culvert would be placed at a 2.4 percent slope and would include a headwall and wingwalls on both the upstream and downstream ends. The total length of the culvert would be 110 linear feet. The estimated cost for this alternative is just less than $0.8 million.

Benefits:

- Minimal disruption to traffic on Colchester Drive

Potential Issues and Concerns:

- Unknown composition of road fill could make pipe jacking difficult or infeasible.

3.2 Selection of Preferred Culvert Alternative

Based on the lower cost and impact to local traffic, the 10-ft diameter culvert pipe jacking alternative is recommended by NHC. However, geotechnical analysis and borings through the road fill are highly recommended to assess whether composition of the road fill will allow pipe jacking. The hydraulic implications of replacing the existing culvert with a fish passable structure are discussed in subsequent sections.

4 DUNCAN CREEK FLOOD REDUCTION ALTERNATIVES

A tiered screening procedure was employed to narrow a wide range of Duncan Creek improvement projects down to a set of actions with the best potential for achieving fish passage, reducing flood frequency, and improving water quality in Duncan Creek. The initial step in the screening procedure involved the development of a wide range of potential projects. A qualitative assessment for a suite of alternatives was used as an initial screening. This was followed by a more quantitative assessment of short-listed concepts employing both hydrologic and hydraulic modeling. Four categories involving 10 project concepts were developed and assessed. The four categories include:

1. Peak creek flow bypass of the flood prone reach
2. Stormwater diversion out of Duncan Creek basin (before it enters the creek)
3. Peak flow reduction through increased detention storage
4. Improve conveyance of the creek in the lower flood-prone area

Each of the project concepts, organized by the preceding four categories, are described below along with an initial qualitative assessment for each. After the descriptions, the results of hydrologic and hydraulic analysis are reported as it relates to each of the potential concepts. The process concludes with a description of the selection procedure for the preferred alternative to reduce flood risk on Duncan Creek.

4.1 Creek Bypasses

Two Duncan Creek bypass alternatives were considered, each involving diversion of peak flows to Puget Sound upstream of the flood prone stream reach.

4.1.1 Hemlock Street Bypass

The Hemlock Street bypass would divert excess peak flows into a new storm pipe and outfall either to the beach or submerged in the Sound.

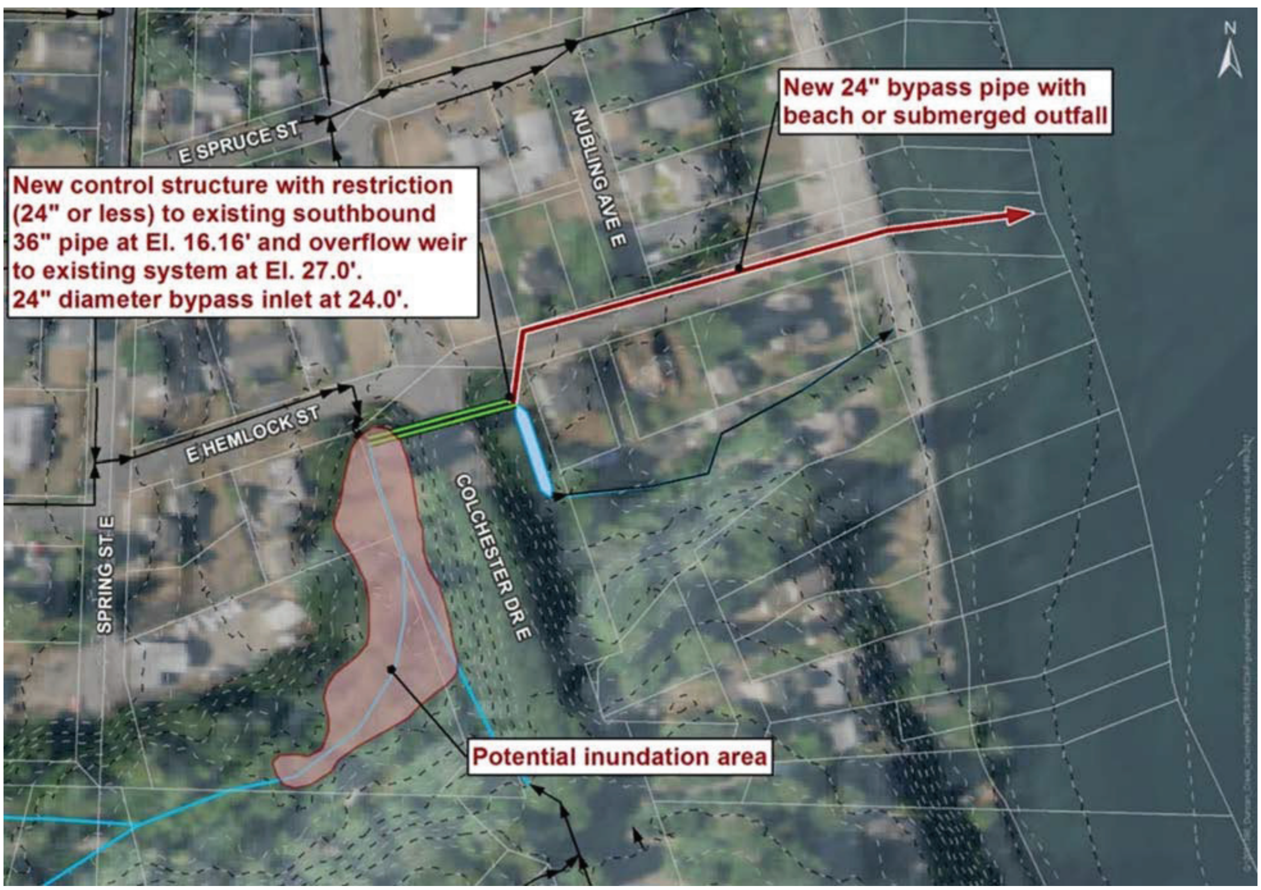

Figure 2: Hemlock Street high flow bypass (4.1.1)

<u>Benefits</u>:

- Flood Reduction: Up to 30 cfs peak flow reduction based on a 2% slope and a 24” concrete pipe. A CMP would provide approximately 40% less flow capacity due to increased roughness. Backing up flow would potentially add detention storage by raising water level has high as elevation 20 ft NGVD upstream of Colchester Drive.

- Habitat: Reduced flashiness and stress on downstream channel habitat.
- Water Quality: Less sediment delivery and erosion of downstream channel.
- Infrastructure: Could dovetail with rehabilitation or replacement of existing failing pipes.

Potential Issues and Concerns:

- Cost and difficulty of permitting new outfall.
- Erosion and sedimentation at beach outfall.
- Opposition from community to new beach outfall.
- Potential utility conflicts along Hemlock St.
- Need for floodproofing and/or property purchase on upstream side of Colchester.
- Very difficult to combine with a fish passable culvert under Colchester.

4.1.2 Bypass to Spruce Street Outfall

This high flow bypass would go east down Hemlock Street and north on Nubling to an existing 18-inch diameter beach outfall near Spruce. Similar to the Hemlock outfall described above, it would include rehabilitation of the existing 36-inch culvert, addition of a hydraulic control that limits or blocks all flow south to an existing oil-water separator. The 18-inch pipe would discharge to the beach or potentially to the Sound via a new submerged outfall.

Benefits:

Flood Reduction: Up to 15 cfs peak flow reduction based on a 2% slope and an 18" concrete pipe. Backing up flow would potentially add detention storage by raising water level has high as elevation 36 feet NGVD on the upstream side of Colchester Drive.

- Habitat: Reduced flashiness and stress on downstream channel habitat.
- Water Quality: Less sediment delivery and erosion of downstream channel.
- Infrastructure: Could dovetail with rehabilitation or replacement of existing failing pipes.

Potential Issues and Concerns:

- Existing 18" pipe likely be too high to connect into for gravity flow as Nubling Ave rises north of Hemlock. Achieving gravity flow would require backing up water levels to approximately elevation 35 feet NGVD29.
- Likely stiff opposition from beachfront property owners due to previous problems prior to Stormwater Park construction.
- Cost and difficulty of permitting new outfall.
- Severe impact to multiple properties west of Colchester Drive requiring purchase.
- Not compatible with a fish passable culvert under Colchester Drive.

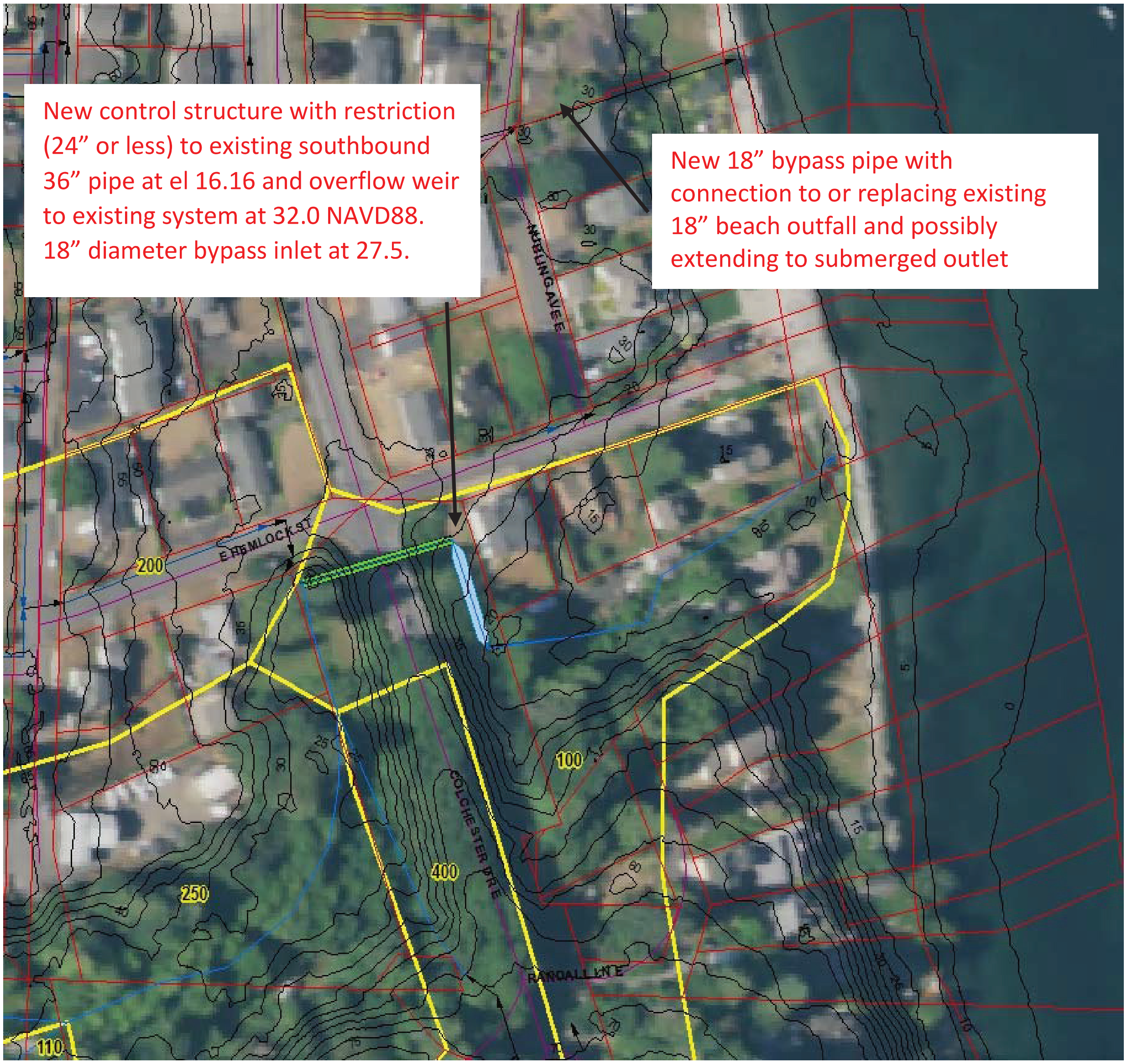

Figure 3: Spruce Street high flow bypass (4.1.2)

4.2 Stormwater Diversion out of Duncan Creek basin

There are four areas within the basin from which stormwater can potentially be diverted and sent either to the Stormwater Park at Colchester Drive and Main Street or to existing marine outfalls at Main Street or Daniel's Loop.

4.2.1 Alaska Avenue Improvement Project

The project will divert stormwater out of the Duncan Creek basin via Alaska Avenue, Madrone Avenue, and Main Street to the Manchester Stormwater Park. It removes storm flows from 22.9 acres consisting of subbasin 321 (Elementary School), part of subbasin 250, and part of 320 north of E Center Street. This is part of an existing project scheduled for construction in 2019 – 2020.

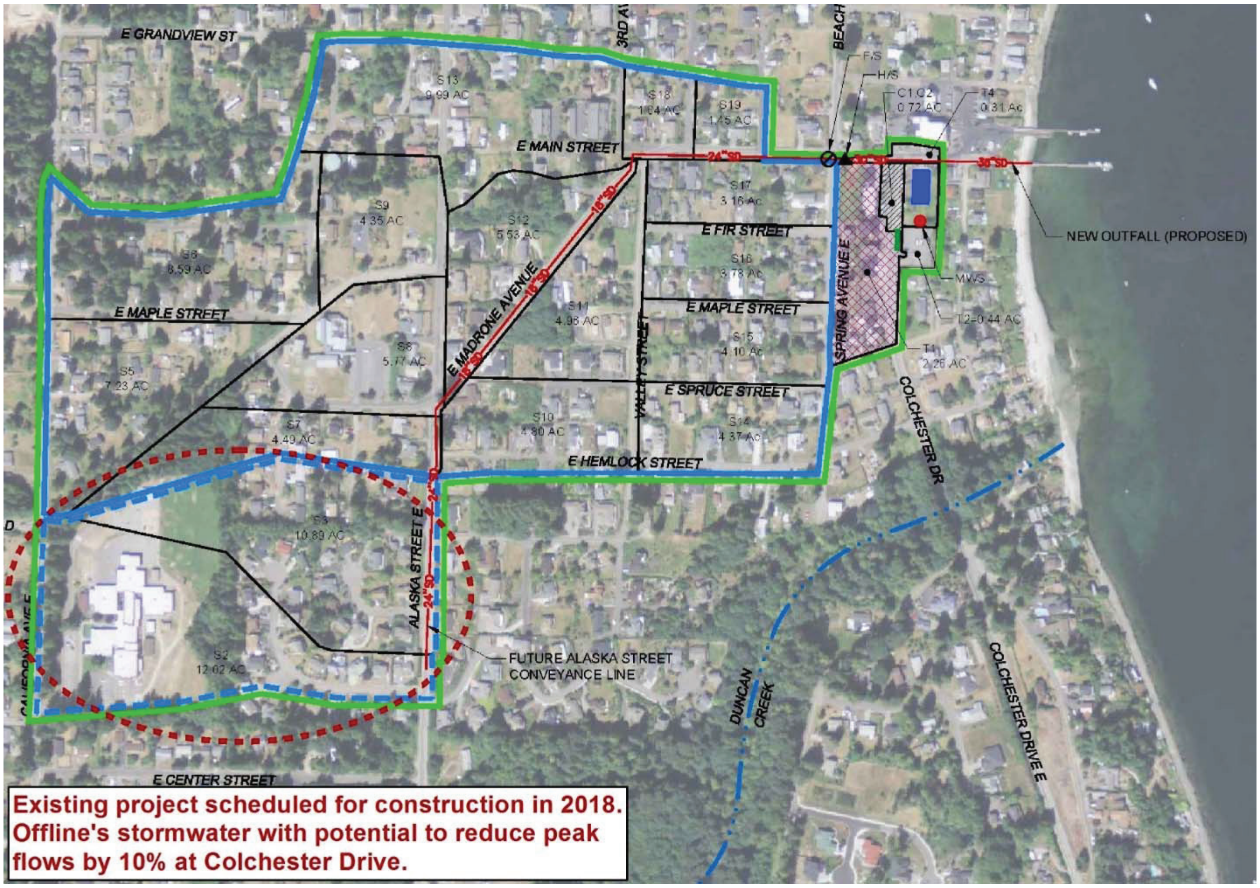

Figure 4: Planned Manchester Elementary and vicinity stormwater diversion – Alaska Avenue Improvement Project (4.2.1)

Benefits:

- Flood Reduction: Potential 10% reduction of peak flow at Colchester Drive.
- Habitat: Reduced flashiness and stress on downstream channel habitat.
- Water Quality: Less erosion downstream of stormwater pond outfall, located at low point in subbasin 310. Reduced sediment delivery and turbidity downstream. Less sediment delivery and erosion of downstream channel. Potential improved performance of existing stormwater pond at outlet of subbasin 310.
- Infrastructure: Dovetails with pedestrian improvements on Alaska Avenue and increases effective use of Stormwater Park treatment. Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

Potential Issues and Concerns:

- Actual benefit to Duncan Creek depends on the capacity of the diversion pipe to the Madrone Avenue system.

4.2.2 Stormwater Capture from Puget Drive and E. Colchester Drive

The project would divert road runoff from the portion of Colchester Drive in Subbasin 400 and all of Puget Drive which crosses subbasins 120, 130, 140, and 150 (see Figure 1). It could also potentially pick up overflow from the outfall of the detention facility in subbasin 360. Flows would be routed along Colchester Drive to the Stormwater Park for discharge from it's outfall or existing outfalls Main Street or E. Daniel's Loop.

Benefits:

- Flood Reduction: This can result in up to a 9% reduction in peak flow at Colchester Drive.
- Habitat: Reduced flashiness and stress on the downstream channel habitat.
- Water Quality: Reduced road runoff lowers pollutant loading. It has the potential to cut off rapid runoff to the steep, exposed ravine embankments at outfalls from subbasins 360 and 400, reducing erosion, turbidity and sediment delivery downstream in Duncan Creek.
- Infrastructure: Possibly use existing stormwater pipe capacity on Colchester Drive from Spruce Street to Manchester Stormwater Park. Increases treatment opportunity at the existing Stormwater Park and is compatible with the replacement of the Colchester Drive culvert with a fish passable culvert.

Potential Issues and Concerns:

- Requires construction of a new storm drain along Colchester Drive from Puget Drive to Spruce Street and possibly further north if capacity of existing pipes is not sufficient.
- May require modifications to drainage systems to fully capture runoff from subbasin 360 or Puget Drive within subbasin 130.

4.2.3 Hemlock Street Stormwater Diversion

Currently a flexible sock delivers stormwater from subbasin 200 (9.7 acres) down the steep left bank of Duncan Creek a short distance upstream of the existing 36-inch Colchester Drive culvert entrance. This is similar to the Colchester-Puget Drive diversion project described above.

Benefits:

- Flood Reduction: Up to 4% reduction in peak flow based on diverted area.
- Habitat: Reduced flashiness and stress on downstream channel habitat.
- Water Quality: Small reduction in road runoff and associated pollutant loading.
- Infrastructure: Possibly use existing stormwater conveyance capacity on Colchester Drive from Spruce Street to Stormwater Park. Increases treatment opportunity at the existing Stormwater Park. Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

Potential Issues and Concerns:

- May not have sufficient grade to route much storm flow to Stormwater Park. Difference in road surface elevations is 4.5 feet over approximately 700 feet suggesting a slope of less than 1%.
- Requires storm drain installation on Hemlock and on Colchester.

4.2.4 Divert Overflows from Alaska Avenue Regional Detention Pond

Overflows from the existing Alaska Avenue Detention Facility would be conveyed through a pipeline via Party Place, Puget Drive, and Colchester Drive similar to options discussed above.

Benefits:

- Flood Reduction: Peak flow reduction could be considerable because the regional facility controls stormwater from approximately 37% of the total drainage area at Colchester Drive. Could work in synergy with pond outlet controls to reduce Duncan Creek peaks by up to 25% downstream of Colchester.
- Habitat: Reduced erosion potential in the downstream creek. If base flows from the facility are still allowed to enter Duncan Creek, then low flows could be maintained during summer months for fish and other habitat purposes.
- Water Quality: Reduction of stream velocity and erosion potential from peak discharges along Duncan Creek resulting in less turbidity and sediment delivery downstream.
- Infrastructure: Compatible with replacement of Colchester Drive culvert with a fish passable culvert or other structure.

Potential Issues and Concerns:

- Possible neighborhood opposition to 400 feet of new pipe that crosses two or three private parcels to reach ROW on Party Place Lane.
- Potential high cost for easements and construction
- Capacity of bypass depends on pipe size slope.

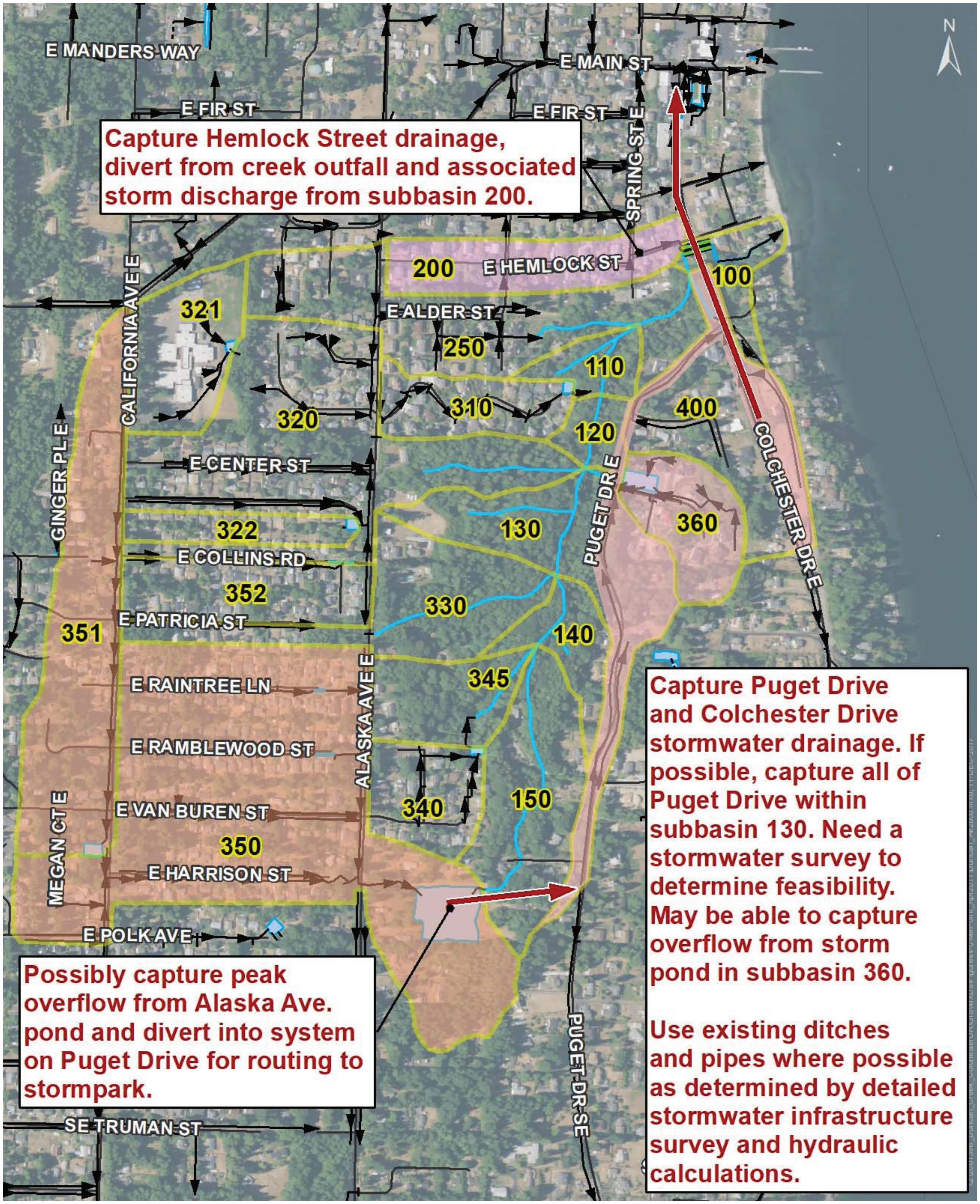

Figure 5: Potential stormwater diversion for: Puget Drive & E. Colchester (4.2.2), Hemlock Street (4.2.3) and Alaska Avenue Regional Detention (4.2.4)

4.3 Detention Storage Options

Reduction in peak flow through increased stormwater detention was evaluated at two locations, the existing Alaska Avenue regional facility and a proposed detention behind the Colchester Drive road embankment.

4.3.1 Expand Detention Storage at Alaska Avenue Regional Pond

Add peak flow storage to the Alaska Avenue facility either by reducing dead storage (water quality pond) or by berming and raising the control structure to add flow control capacity. A 1-ft increase in maximum water surface elevation would add an approximately 1.5 ac-ft for a maximum of 6.5 ac-ft of dynamic storage. Re-purposing water quality dead storage for flow control adds between 1.0 and 1.5 ac-ft per foot of depth.

<u>Benefits:</u>

- Flood Reduction: Peak flow reduction downstream of Colchester would depend on the amount of added dynamic storage but is expected could range from 10% to 25%. By itself, the regional facility controls stormwater from approximately 37% of the total drainage area at Colchester Drive which limits its capacity to control downstream flows.
- Habitat: Reduced flashiness and stress on downstream channel habitat over full length of creek.
- Water Quality: Reduction of stream erosion potential from peak discharges along Duncan Creek resulting in less turbidity and sediment delivery downstream.
- Infrastructure: Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

<u>Potential Issues and Concerns:</u>

- Converting existing wetpond storage to dynamic storage will reduce water quality treatment.
- Raising the operating level of the facility may cause drainage and groundwater problems for neighboring properties.
- The ability of storage at the regional facility to reduce peaks at Colchester Drive is limited by its stormwater capture area which is approximately 37% of the basin.

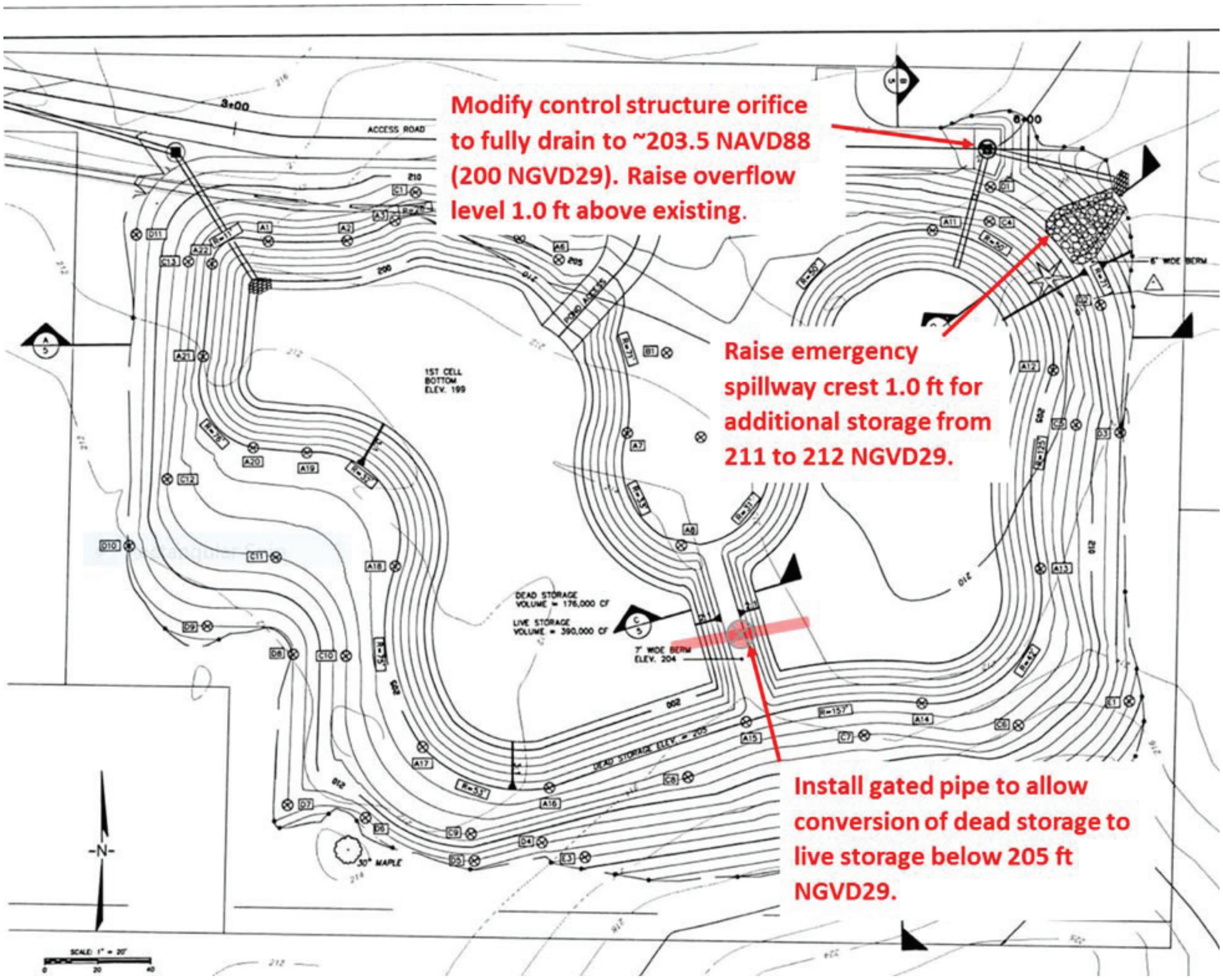

Figure 6: Alaska Ave Regional pond detention enhancement concept (4.3.1)

4.3.2 Increase Storage Behind Colchester Drive Road Fill

Use a control structure to detain water on the upstream side of Colchester Drive similar to creek diversion options, but without a high flow diversion pipe. Excavation and berming could provide between 0.5 and 1.5 ac-ft of detention storage.

<u>Benefits:</u>

- Flood Reduction: Outlet could be tuned to control flow downstream of Colchester Drive and reduce peaks.
- Habitat: Reduced flashiness and stress on channel habitat downstream of Colchester Drive.
- Water Quality: Less sediment delivery and erosion of downstream channel.
- Infrastructure: Compatible with rehabilitation of existing culvert and piping system. A replacement culvert would need a low inlet to engage storage.

Potential Issues and Concerns:

- Need to mitigate potential impacts from both excavation and higher water level on Water District and residential property on the upstream side of Colchester Drive associated with excavation and raising water levels.
- Poor compatibility with WDFW stream simulation design guidelines for fish passage.
- Potential seepage through Colchester Drive road fill.
- Ponding of water adjacent to road may present a public safety concern.

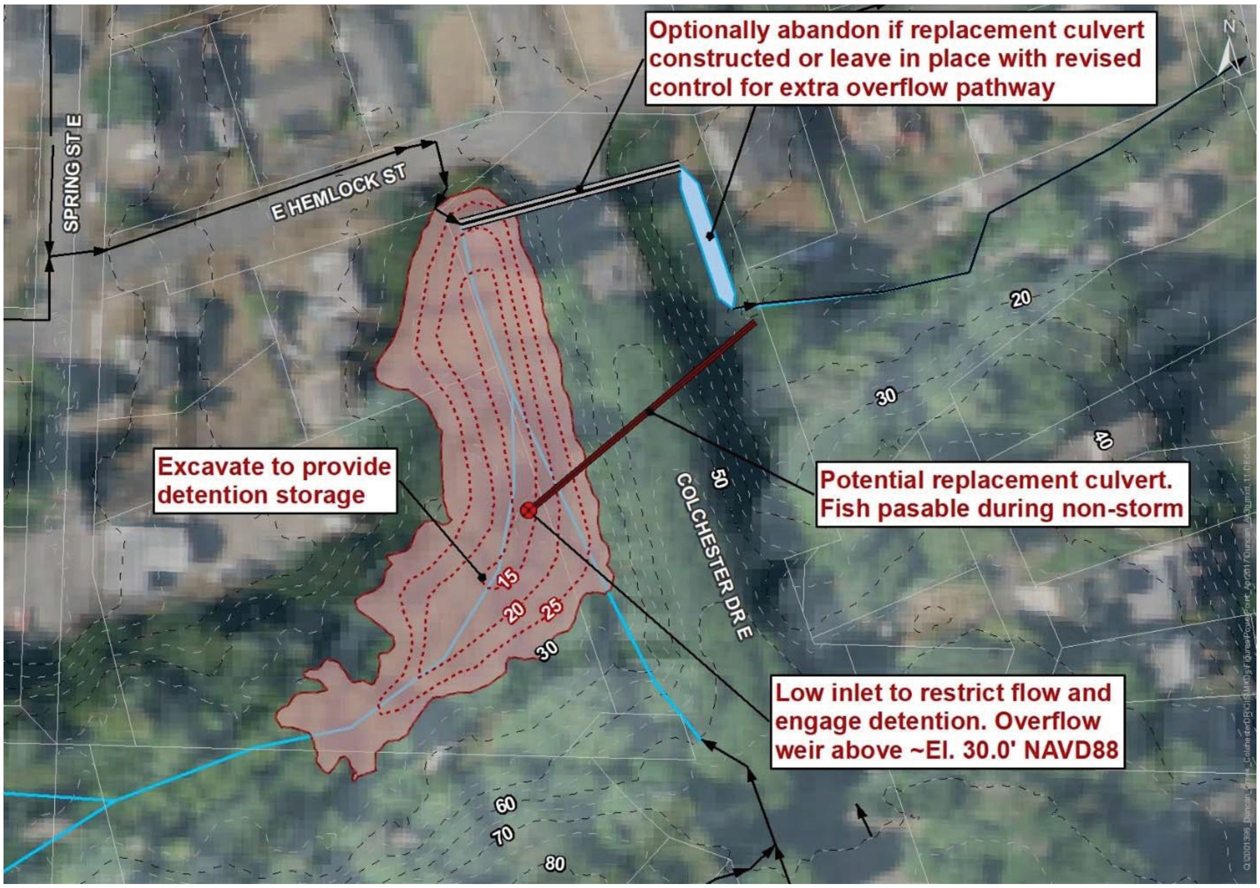

Figure 7: Colchester road fill instream detention concept (4.3.2)

4.3.3 Replace Existing Colchester Drive Culvert with Bioswale Retention

Installation of a new fish passable culvert beneath Colchester Drive eliminates the need for the existing 36 inch culvert and downstream pipe network that currently conveys Duncan Creek. The existing culvert would be plugged and abandoned, while the downstream pipe network is to be removed. Flow from Hemlock Street, representing stormwater from subbasin 200 (9.7 acres), would flow into a bioswale retention system and treat it for contaminants prior to its infiltration into the ground. This alternative is similar to the Hemlock Street Stormwater Diversion described previously, but would eliminate the need for pipeline construction.

Benefits:
- Flood Reduction: Up to 4% reduction in peak flow based on the area diverted.
- Habitat: Reduced flashiness and stress on downstream channel habitat.
- Water Quality: Bioretention system would provide contaminant removal for pollutant loading associated with road runoff.
- Infrastructure: Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

Potential Issues and Concerns:
- May not have sufficient area for bioretention system.
- Soils would need to be tested to ensure proper function with a bioretention system.

4.4 Increase Flood Conveyance Downstream of Colchester Drive

Two approaches to conveyance downstream of Colchester were considered, a complete redesign of the channel with both a larger cross-section and habitat features and a more targeted approach based on relieving selected hydraulic pinch points within the flood-prone reach.

4.4.1 General Channel Enlargement and Habitat Improvement

Benefits:
- Flood Reduction: Lower water levels during peak flow events.
- Habitat: Addition of a floodplain bench could be integrated with habitat features.
- Water Quality: Reduction of stream velocity and erosion potential from peak discharges along Duncan Creek resulting in less turbidity and sediment delivery downstream.
    - Infrastructure: Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

Potential Issues and Concerns:
- Project is on private property outside of County ROW. Property owner should consider engaging Kitsap Conservation District or other agency to pursue grant funding for channel improvements.
- Existing large trees, hard landscape features, and structures near the stream banks makes this approach very challenging.
    - Likely to encounter resistance from property owner and possible need to purchase high value property adjacent to the creek.

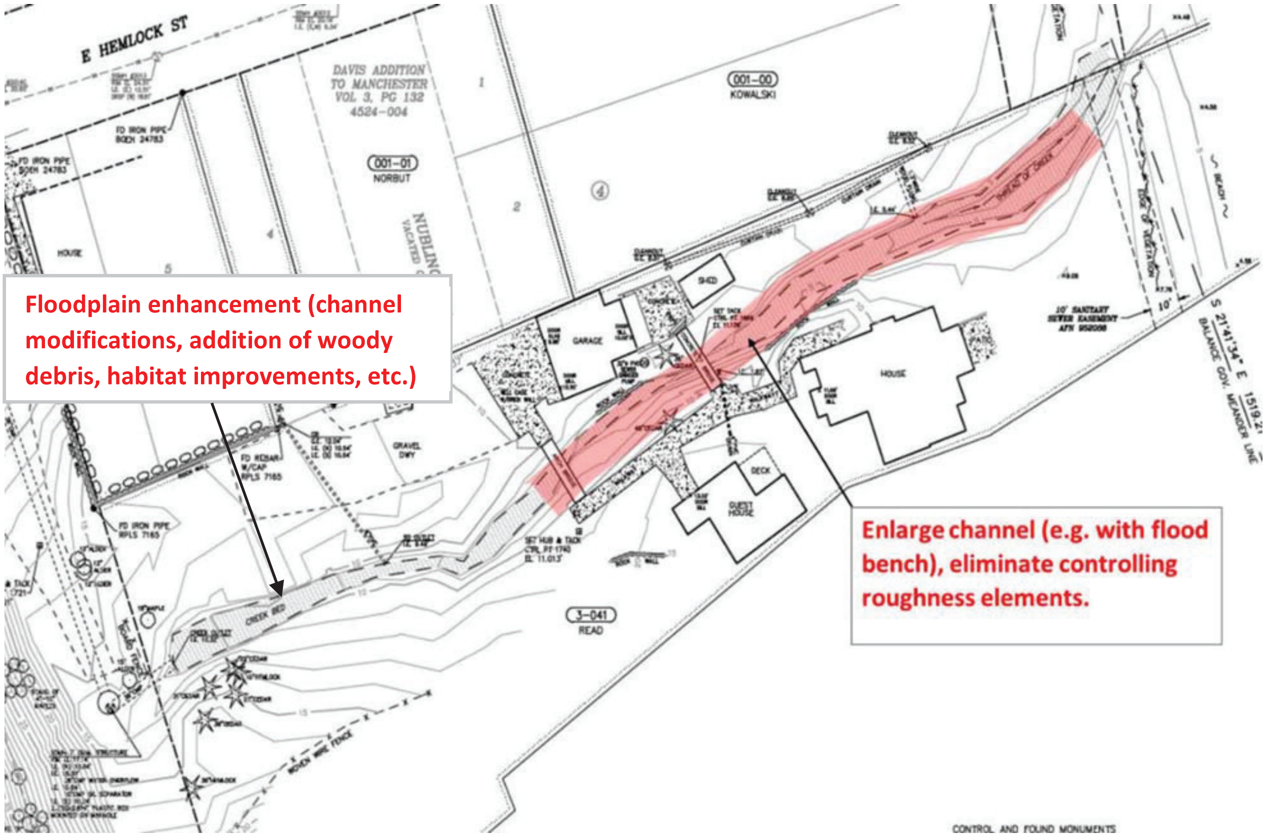

Figure 8: Creek widening conveyance improvement concept (4.4.1)

4.4.2 Selective Roughness Reduction and Flood Proofing

Based on survey of the channel downstream of Colchester Drive, identify and modify hydraulic controls and selectively raise bank elevations with landscape elements at flood breakout points.

<u>Benefits:</u>

- Flood Reduction: Greatly reduce the frequency of nuisance flooding which occurs at a 2-yr to 5-yr average interval currently.
- Habitat: Minimal impact to habitat.
- Water Quality: Minimal impact to water quality.
- Infrastructure: Compatible with replacement of Colchester Drive culvert with a fish passable or other structure.

<u>Potential Issues and Concerns:</u>

- Project is on private property outside of County ROW. Property owner should consider engaging Kitsap Conservation District or other similar agency to pursue grant funding for channel improvements.
- Potential resistance from property owner if not combined with other measures to reduce peak discharge rates.

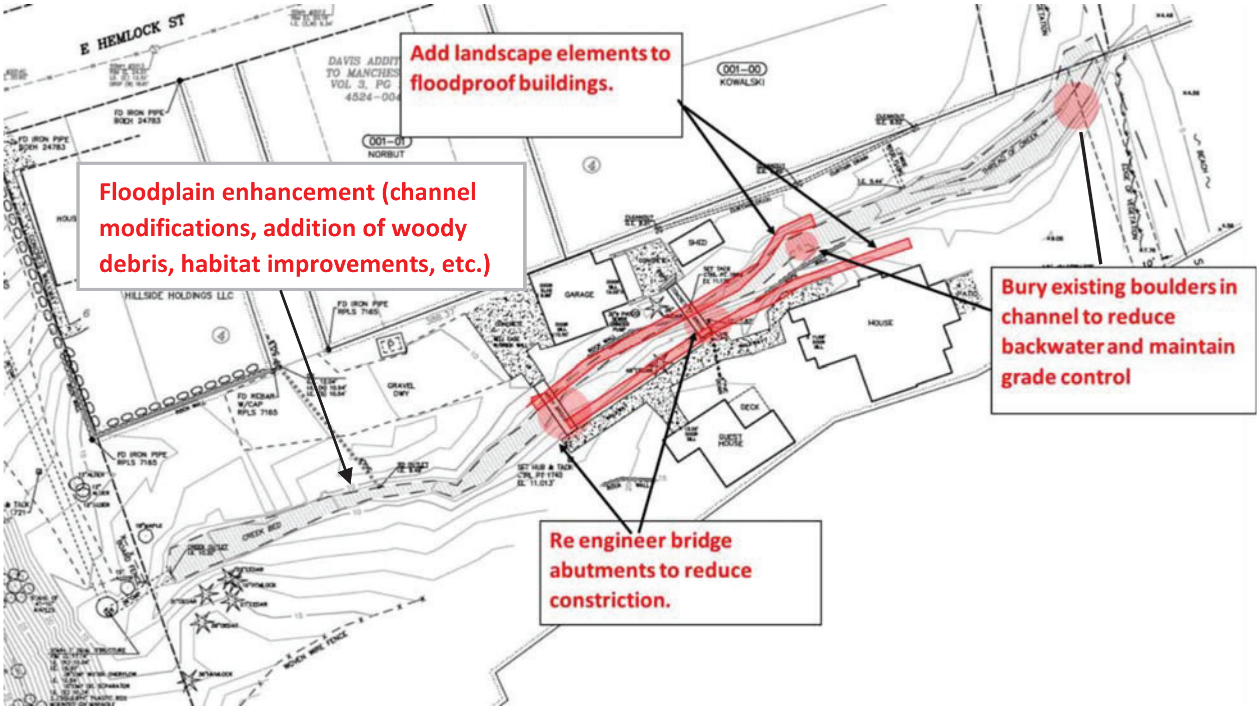

Figure 9: Targeted roughness reduction and floodproofing (4.4.2)

5 HYDROLOGIC ANALYSIS OF THE DUNCAN CREEK BASIN

NHC developed an HSPF hydrologic model of the entire Duncan Creek basin. The model was developed using overlays of GIS data including aerial photos, LiDAR-based topography, soils, drainage layers, parcels, hydrography, supplemented with reports, facility design drawings, and information provided by County staff. As shown by the yellow polygons in Figure 1, the model breaks the Duncan Creek watershed up into 19 subbasins reflecting areas which drain to all major outfall points to Duncan Creek plus six areas immediately adjacent to the creek.

5.1 HSPF Model Calibration

HSPF is a continuous hydrologic model that requires a continuous, detailed precipitation record and supplemental meteorological data to simulate runoff processes and stream flow within a watershed. Kitsap County recorded 15-minute stream flow data at the upstream end of the flood-prone stream reach from October 2005 to September 2009 and recently re-initiated data collection in November 2016. Model calibration requires contemporaneous stream flow and precipitation data; however, no short timestep precipitation data were available within or near the Duncan Creek basin. The closest sub-daily rainfall record available is from King County's 47u gage located approximately 4.5 miles away from the Duncan Creek basin centroid at the northern tip of Vashon Island. This record runs from October 1998 to present. While there should be no expectation of consistently matching recorded stream flow hydrographs using a precipitation record at this distance from a small, flashy stream basin like Duncan

Creek, some good matches to flood events were nevertheless achieved. Figure 10, below, shows matches of gaged and simulated monthly hydrographs from both the earlier period of record and the recent 2017 water year[5] record. With some exceptions which are likely attributable to non-representative rainfall, the model hydrographs track the recorded hydrographs quite well. Note that the black line represents the gage data and the purple line the simulated hydrograph.

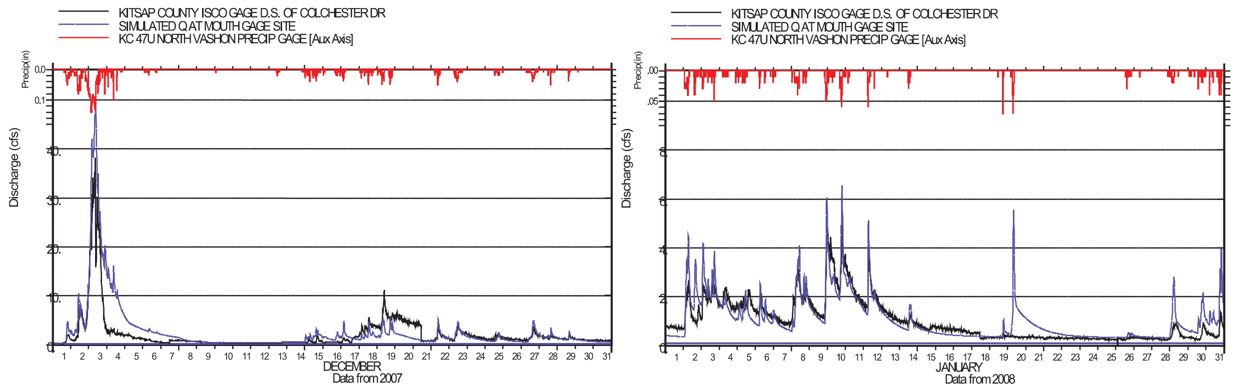

Figure 10: Comparison of simulated hydrograph to gage data from an earlier period of record

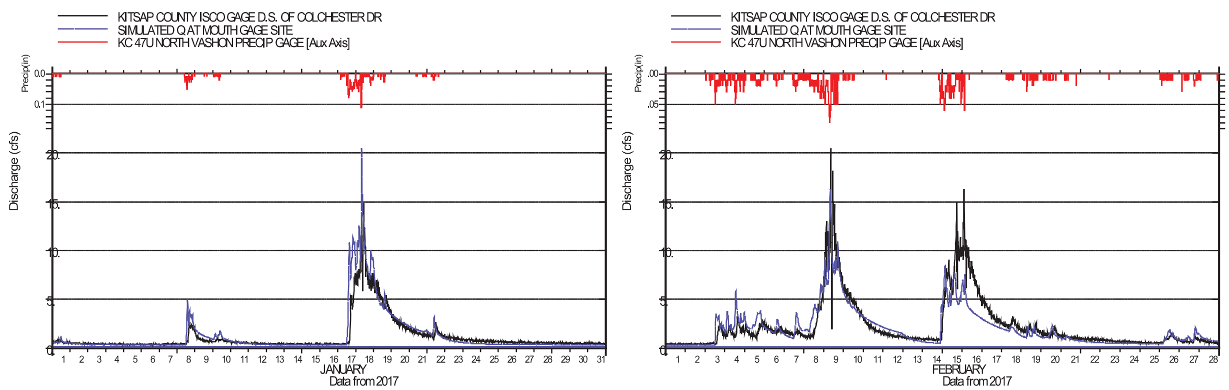

Figure 11: Comparison of simulated hydrograph to gage data from recent period of record

5.2 Flood Frequency in Flood-Prone Reach

Based on the available precipitation record from the North Vashon rain gage, the model was run continuously for 19 water years. A log-Pearson flood frequency curve based on simulated peak annual flows was fit to the available data. Results are shown in the figure below. Peaks range from approximately 22 cfs at the 2-year average recurrence to 79 cfs at the 100-yr.

[5] Water Year is defined as the 12-month period October 1, for any given year through September 30, of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months.

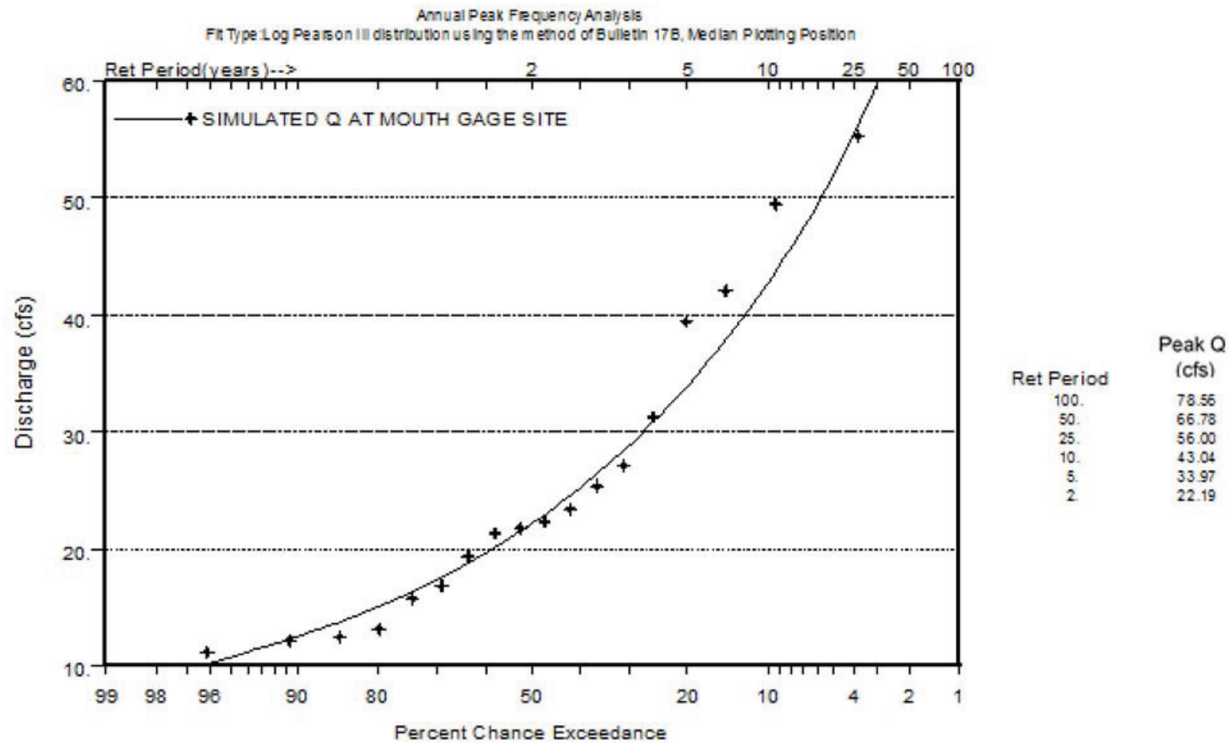

Figure 12: Existing condition flood frequency curve downstream of Colchester Drive

6 HYDRAULIC ANALYSIS OF FLOOD-PRONE REACH

Using a base map provided by the County (2013), combined with LiDAR data, field reconnaissance notes and photos, and anecdotal flood information provided by the land owner, NHC constructed an existing condition HEC-RAS hydraulic model of Duncan Creek. The model includes the open channel, flood-prone reach, existing control structures and 36-inch pipe and culvert system, as well as the open channel reach within the Manchester Water property upstream of Colchester Drive. During field reconnaissance, NHC noted several potential local pinch points in the flood-prone reach including boulders in the channel, rock weirs, and places where tree trunks narrow the width of the channel; however, no detailed cross-section survey data was available with which to represent these local channel constrictions.

6.1 Calibration of Hydraulic Model

The hydraulic model was calibrated to a recent flood event that occurred on February 9, 2017. A Kitsap County flow gage located at the head of the flood prone open channel reach recorded a maximum discharge of 20.5 cfs on this day, slightly less than a 2-yr peak annual flow event. The owner commented that water had flowed overbank and contacted the foundation of his garage. By applying typical roughness coefficients and representing a rock weir located downstream of the lower foot bridge as a high point in the channel, the model reproduced a left bank, channel overflow near the upstream side of the lower footbridge. This would have resulted in the high water observed by the owner on the garage foundation.

6.2 Effect of Rock Weir

Hydraulic modeling and analysis of the flood-prone reach indicates that the rock weir, located downstream of the lower foot bridge on the Read property, exacerbates frequent flooding under existing conditions. If the weir is removed or buried, flood frequency could be reduced by a factor of four (from an average of once in less than two years to once in approximately eight years). Property owner should consider engaging Kitsap Conservation District or other similar agency to pursue grant funding and implement this change.

7 SELECTION AND ANALYSIS OF A PREFERRED ALTERNATIVE

On May 4, 2017, NHC and Kitsap County stormwater program staff met to discuss project alternatives discussed above. Based on considerations of cost, permitting feasibility, neighborhood acceptance, and compatibility with installation of a fish passable culvert under Colchester Drive, alternatives that incorporate high flow bypasses directly from Duncan Creek were excluded from further consideration. Additionally, construction of detention storage behind the Colchester Drive was also determined to have low compatibility with fish passage and high impact on property owners. This left stormwater bypasses, enhancement of detention storage at the Alaska Avenue Pond, and conveyance improvement in the flood-prone reach for further consideration.   Among the stormwater bypass alternatives, the Alaska Avenue Pond overflow bypass was considered least feasible due to the need to acquire easements and build a pipe to connect pond overflows with storm drain conveyance along Puget Drive. General channel widening coupled with habitat enhancement along the entire length of the channel downstream of Colchester Drive was discarded as an option because it would require removal of mature trees and hard landscape improvements, and would not be acceptable to the property owner.   However, some measure of improvements to this reach remain an option, but would need to be implemented by the property owner, likely in collaboration with the Kitsap Conservation District. Possible measures include targeted conveyance improvement and low flood walls to reduce the frequency of flooding under existing conditions. Kitsap County would not undertake such a project since both sides of the creek are privately owned. However, these improvements can be suggested to the owner along with any appropriate assistance programs.

Table 1: Ranking of stormwater control concept alternatives

		Enhance Stream quality/stability	Relieve Flooding	Compatibility with Fish Passage	Feasibility (permitting & cost)	Impact to property owners	Total Score	Preferred by County
4.1.1	Creek Bypass to new Hemlock Outfall	2	2	1	1	1	7	No
4.1.2.	Creek Bypass to new/old Spruce Outfall	2	2	1	1	1	7	No
4.2.1	Storm bypass – Alaska Ave. Improvement Project	2	2	3	3	2	12	Yes
4.2.2	Storm bypass-Puget Dr. and Colchester Dr.	2	2	3	3	2	12	Yes
4.2.3	Storm bypass- Hemlock St	2	2	3	3	2	12	Yes
4.2.3	Storm bypass-Puget Dr. and Colchester Dr.	2	2	3	3	2	12	Yes
4.2.4.	Storm Bypass- Alaska Ave Regional Detention overflow	2	2	3	2	1	10	No
4.3.1.	Expand Detention- Alaska Ave Regional Pond Retrofit	3	3	3	2	3	14	Yes
4.3.2	Expand Detention- Colchester Drive Rd fill	2	3	1	2	1	9	No
4.3.1	Bioretention swale for Hemlock Street flow	2	2	3	3	2	12	Yes
4.4.1.	Stream Conveyance- enlarge entire stream channel	2	2	3	1	1	9	Yes[1]
4.4.2	Stream Conveyance- relieve choke points, flood proof.	2	2	3	3	2	12	Yes[1]

[1]This would not be a County project as both sides of the creek are privately owned.

7.1 Evaluation of the Preferred Flood Reduction Alternative

NHC evaluated the hydrologic impact of implementing a preferred solution that combines the three-highest ranking stormwater bypass alternatives with expansion of detention capacity at the Alaska Avenue regional pond and replacement of the existing culvert, chambers, and pipe system with a stream simulation culvert under Colchester Drive. Intuitively, it would seem that installation of a free-flowing stream simulation culvert would raise peak flows in the flood prone stream reach; however, the existing 36-inch detention pipe system and hydraulic controls do not engage a significant amount of storage. As such, replacement of this system causes only a modest increase in peak annual flows as shown in the following table. Additionally, peak flows downstream of the Colchester Drive culvert can be reduced by implementing the preferred projects discussed previously (stormwater runoff diversion and increased storage at the Alaska Avenue pond).

Table 2: Effect of culvert replacement on peak annual flow downstream of Colchester Dr

Avg. Annual Recurrence (yrs)	Peak Quantile Existing (cfs)	Peak Quantile Stream Simulation (cfs)	Increase over existing
2	22.2	22.2	0.0%
5	34.0	34.4	1.2%
10	43.0	44.2	2.8%
25	56.0	58.6	4.6%
50	66.8	70.8	6.0%
100	78.6	84.5	7.5%

To that end, the preferred solution (including the replacement culvert) was simulated using the HSPF model to determine the overall impact on peak flows in the flood prone reach. In this scenario, it is assumed that the existing Alaska Avenue pond is retrofitted to convert 1.0 feet of dead storage to live storage and that the maximum depth in the pond is increased by an additional foot. This increases the total live storage from approximately 6.0 ac-ft to 8.0 ac-ft. The preferred stormwater diversion projects are assumed to fully re-route impervious area runoff from select areas out of the Duncan Creek basin to Manchester Stormwater Park and/or marine outfalls in that vicinity. Additionally, for conservatism, this model scenario adds impervious surface runoff associated with the paving of road shoulders to the Alaska Avenue pond inflows. The aggregate impact of these projects on Duncan Creek peak flows is summarized in Table 3.

As shown in table, *reductions* across the spectrum of peak annual flow quantiles range from 49% at the 2-yr level to 14% at the 100-yr. More significantly, the 20.5 cfs discharge that produced high water on February 9, 2017 would have a 1 in 5 year recurrence level with the preferred projects in place (with no change in the channel conditions within the Read property). If the rock weir is removed, a 40 cfs discharge would be required to produce the maximum water level estimated to have occurred on February 9, 2017 (~11.5 feet NAVD88). This is a 1 in 8 year event with no basin projects completed and a 1 in 25 year event with all preferred basin projects constructed including a stream simulation culvert.

Table 3: Effect of preferred concepts combined with culvert replacement on peak flow quantiles downstream of Colchester Dr			
Avg. Annual Recurrence (yrs)	Peak Quantile Existing (cfs)	Peak Quantile all projects including Colchester Culver replacement (cfs)	Increase over existing
2	22.2	11.4	-48.6%
5	34.0	19.7	-42.1%
10	43.0	27.3	-36.5%
25	56.0	40.1	-28.4%
50	66.8	52.3	-21.7%
100	78.6	67.4	-14.2%

7.2 Potential Detention Facility on the NW Corner of Center Street and Alaska Ave

Following evaluation of the preferred alternative, Kitsap County staff requested that NHC investigate the potential benefits of installing a detention facility on the west side of Alaska Avenue in subbasin 302. Subsequent to this investigation, the site was purchased and the property owner is now pursing development options. Because of this, the location no longer provides an opportunity for flow reduction and the findings provided in Section 7.2 are for informational purposes only.

The location of interest is an undeveloped lot on the north side of Center Street (Parcel #: 4591-001-001-0004). Field reconnaissance of the site suggests that it is well-suited as a potential detention facility because it includes a low-lying area that collects stormwater behind the Alaska Avenue road fill and passes it under Alaska Avenue via an existing 18-inch CMP culvert to a left bank ravine of Duncan Creek. This ravine has experienced severe erosion with consequent sediment delivery to Duncan Creek.

While this detention facility was not included in the preferred alternative as described above, NHC used the calibrated Duncan Creek HSPF model to investigate potential benefits of such a facility in controlling peak flows and erosive flow durations in the tributary ravine to Duncan Creek (sub-basin 320 discharge point). Three scenarios were analyzed: 1) existing land use and stormwater routing conditions (black line in the following graphs), 2) existing basin and routing conditions but with the addition of a 3.0 ac-ft detention pond at Alaska Ave (purple line), and 3) forest conditions (red line). Figures 13 and 14 summarize the results.

As shown in the first graphic, the assumed detention pond has the potential to almost completely reverse the forest-to-existing increases in peak annual flow at average annual recurrence intervals between the 2-yr and 10-yr , as well as substantially reducing the increases for more rare and extreme events. The second graph illustrates benefits of detention to reduce flow durations. The horizontal lines represent the forested condition 2-, 5-, 10-, and 25-yr peak quantiles. Although, the forested flow duration curve has not been matched by the detention scenario, reductions in the existing condition durations range from 45% at the forested 2-yr level to nearly 100% at the 10-yr level. Should the County decide to move ahead with such a facility, it would make sense to design the pond outlet hydraulics to minimize the duration of discharges above flow rates that cause erosion in the existing ravine downstream. This target would be used in lieu of forest condition flow durations which may no longer be relevant due to scour and enlargement of the tributary channel from under-detained stormflows in recent decades. Appropriate hydrologic targets could be estimated with a field-based geomorphic and sediment assessment of the ravine.

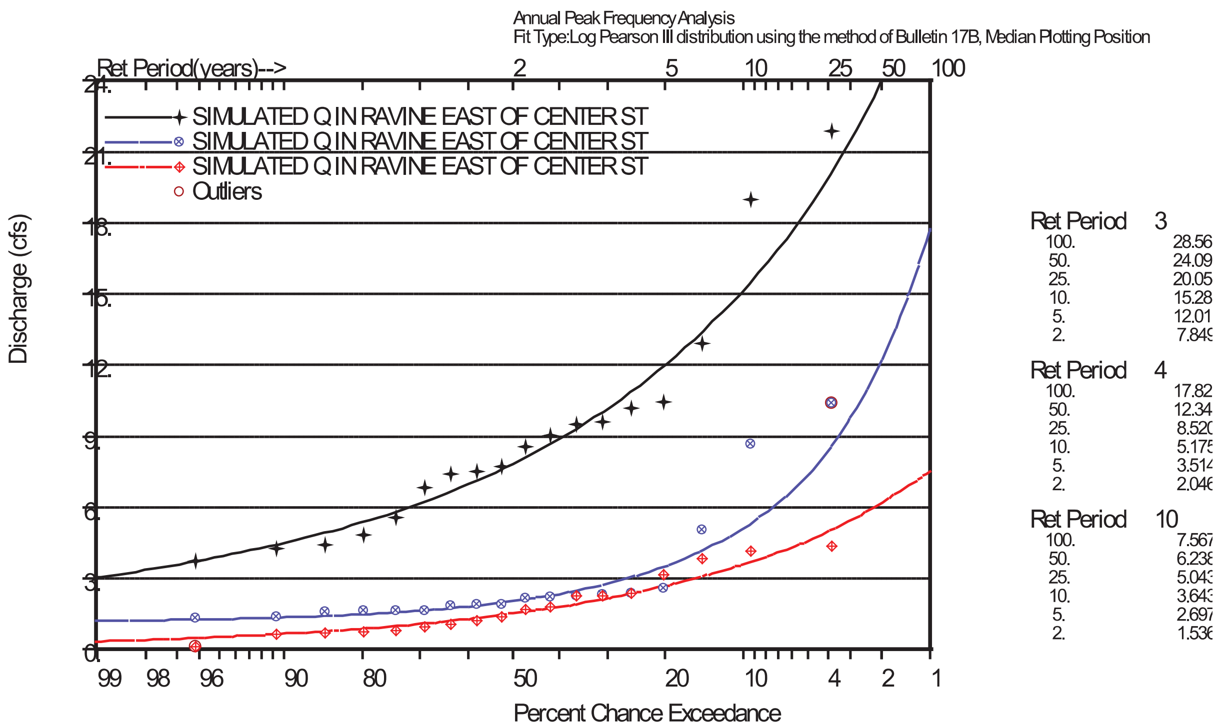

Figure 13: Flood frequency comparison for subbasin 320 discharge to left bank ravine of Duncan Creek

In addition to reducing peaks and erosive flow durations in the tributary ravine, a detention pond at this location has the potential to also reduce peak annual flow quantiles in the flood prone reach downstream of Colchester Drive by between 5% and 20% between the 2-yr and 25-yr average annual recurrence intervals.

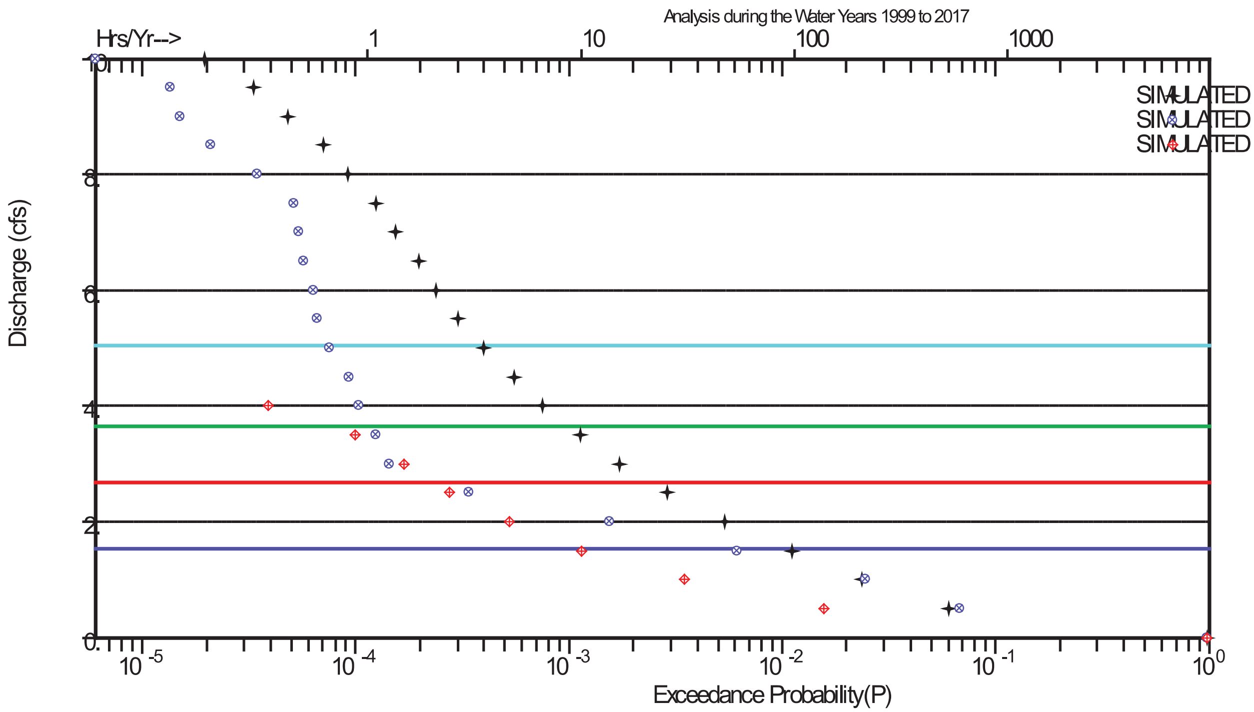

Figure 14: Flow duration comparison for subbasin 320 discharge to left bank ravine of Duncan Creek

8 SUMMARY AND CONCLUSIONS

The County is interested in replacing the aging 36-inch culvert and associated piping system that convey Duncan Creek under Colchester Drive to an open channel reach that discharges to Puget Sound. In recent years there have been frequent complaints of chronic flooding where the creek flows within a single residential parcel that includes buildings near both banks of the creek. The property owner has expressed an interest in reducing peak storm flows in Duncan Creek and is concerned that replacement of the existing culvert and piping system will increase the frequency of flooding on his property.

NHC performed a basin reconnaissance which included examination of the channel within the flood-prone property, developed and evaluated basin-wide project concepts for peak flow reduction, and built both hydraulic (HEC-RAS) and hydrologic (HSPF) models to analyze existing and potential future flood frequency.

Application of the hydraulic model to existing conditions suggests that a rock weir within the flood prone property downstream of Colchester Drive increases the incidence of frequent flooding. Removal of this hydraulic constriction would reduce the frequency of incipient flood levels by a factor of four if no other actions were taken. It was also found that the existing culvert and pipe system has insufficient storage to attenuate much of the peak flows downstream of the Colchester Drive. Replacement of this infrastructure with a free flowing, stream simulation culvert would not increase in 2-yr peak flow and only increase the 100-yr peak by about 10%.

Working with County staff, NHC identified a series of preferred basin-wide projects involving increased regional detention capacity at the Alaska Avenue facility, diversion of stormwater runoff from several basin areas to the Manchester Stormwater Park or nearby marine outfalls, and bioretention of runoff within the project footprint. Modeling demonstrates that the cumulative hydrologic impact of these preferred projects in combination with removal of the rock weir in the flood-prone channel and installation of a stream simulation culvert would reduce the frequency of incipient flooding from less than 1 occurrence in 2 years on average to approximately 1 occurrence in 25 yrs.

Based on this study of the Duncan Creek basin, NHC recommends the following:

1. Encourage the property owner experiencing flooding, located downstream of Colchester Drive, to remove the hydraulic constriction caused by the rock weir in the vicinity of the downstream footbridge and do some targeted flood proofing.
2. Replace the Colchester Drive culvert with a 10-ft diameter stream simulation culvert in conjunction with implementation of one or more of the preferred projects that reduce peak flow in the creek.

9 CLOSURE

DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Inc. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of Kitsap County Public Works and their authorized representatives for specific application to the Duncan Creek Culvert Replacement and Flood Reduction Alternatives Analysis in Kitsap County, WA. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Inc. No other warranty, expressed or implied, is made. Northwest Hydraulic Consultants Inc. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than Kitsap County Public Works.

Sincerely,

Northwest Hydraulic Consultants Inc.

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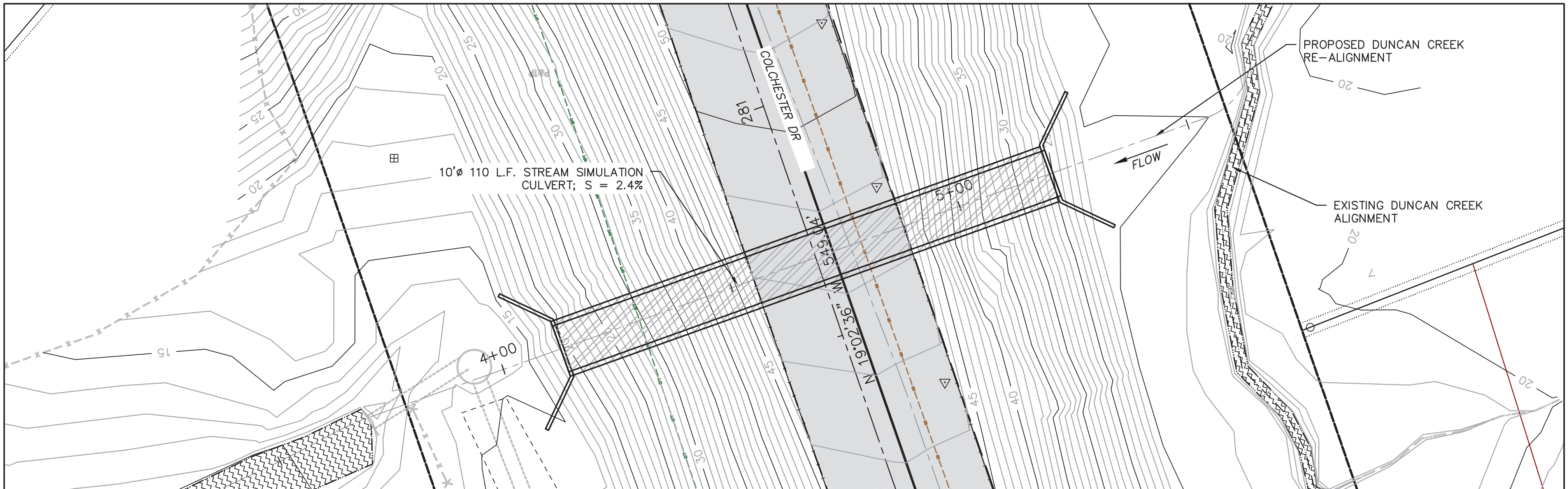

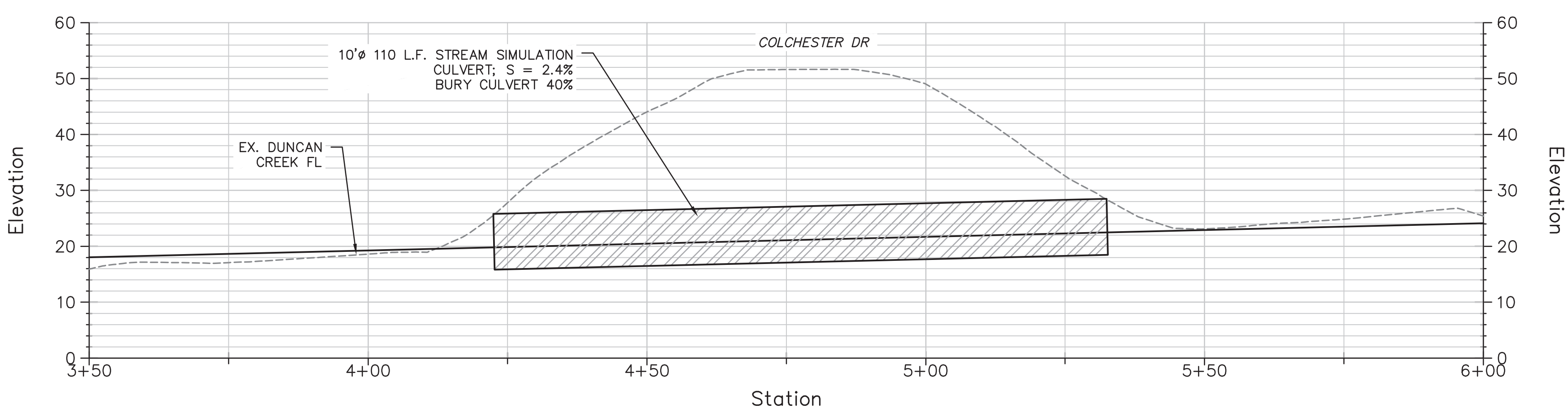

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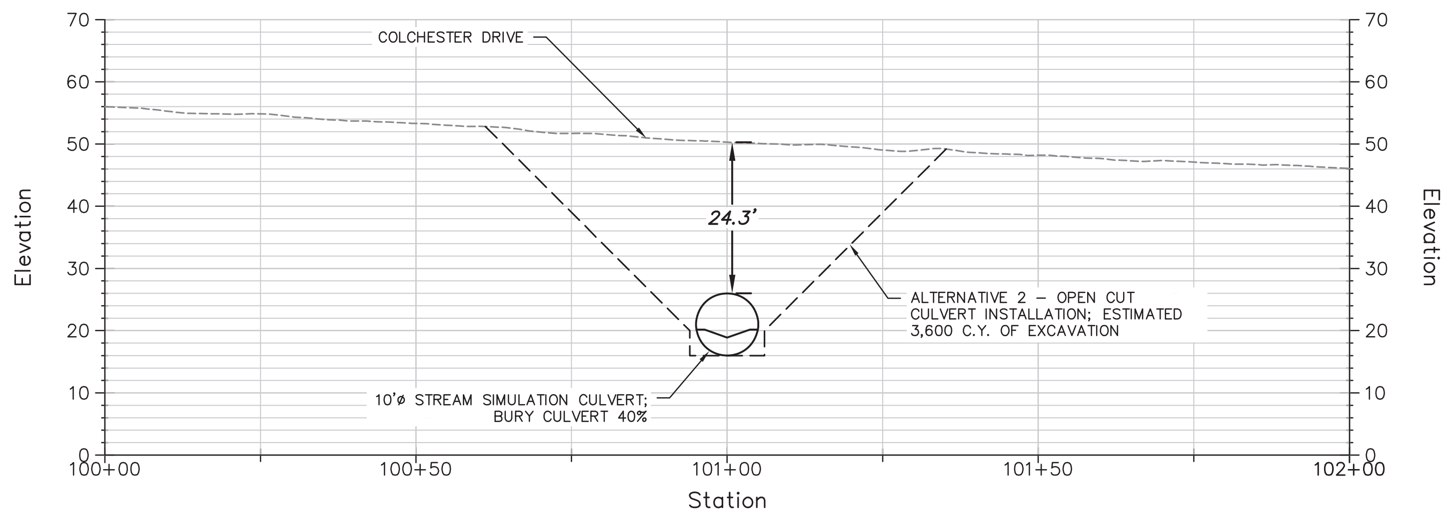
DUNCAN CREEK ALTERNATIVES

PROPOSED CULVERT PLAN & PROFILE

FIGURE A1



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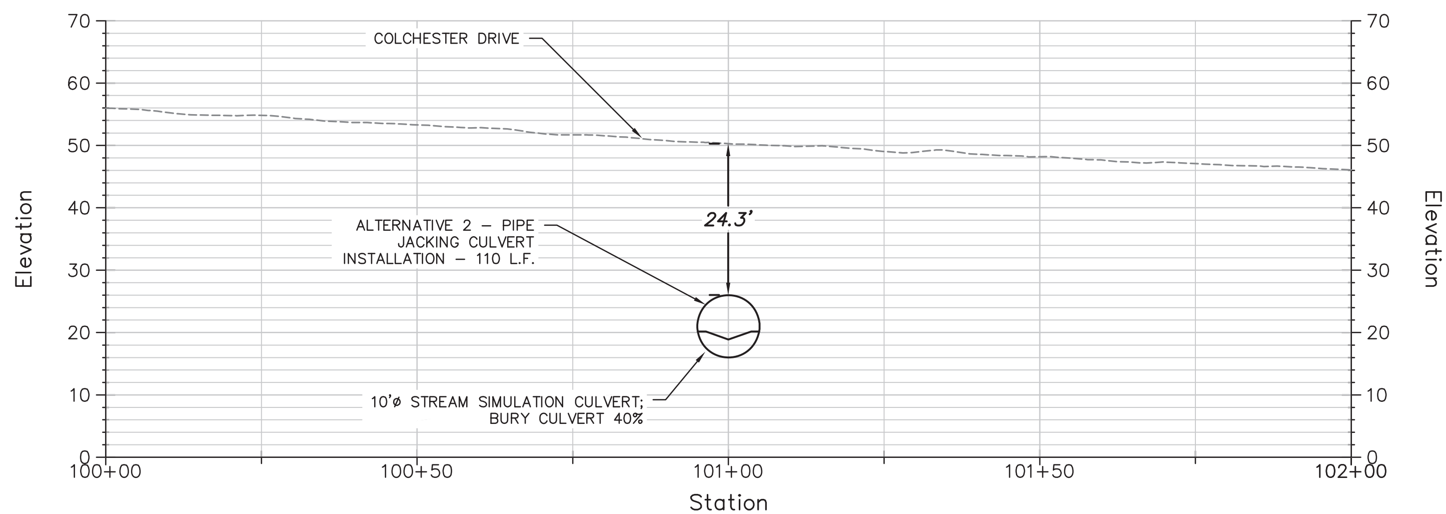
DUNCAN CREEK ALTERNATIVES

PROPOSED CULVERT - OPEN CUT ALTERNATIVE
SECTION VIEW

FIGURE A2



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DUNCAN CREEK ALTERNATIVES

PROPOSED CULVERT - JACKING ALTERNATIVE
SECTION VIEW

FIGURE A3