Appendix B

Hydraulic Modeling Update and Evaluations

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Appendix B.1

Description of Models Used for King County CSO Control Planning

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Description of Models Used for Metro/King County CSO Planning

King County's approach to modeling has changed over time. This has resulted from improvements in the science of modeling and available models, as well as improved information about the conveyance system. The history of this effort is summarized in Table 1. A description of each modeling effort follows.

1979 CSO Control Program

In this program, models specifically developed for the 1976 Metro 201 Facilities plan were used. These included a model known as HYDRO to generate runoff from storms.

HYDRO used a synthetic unit hydrograph technique to calculate surface runoff from rainfall. The synthetic unit hydrograph is a triangular hydrograph of the flow that would result from one inch of rain in a ten-minute period. Unit hydrograph shape was dependent on the shape of the area from which runoff was being calculated. Two sets of independent calculations were performed for impervious and pervious surfaces.

Sanitary sewage flows were represented in the 1979 modeling by diurnal hydrographs adjusted in magnitude based on the land use of individual tributary areas. A base infiltration factor (usually 1,100 gpad, but adjusted for measured flows) was added to compute base sewage flow. Runoff computed by the unit hydrograph technique was then added to base wastewater flows.

The total flow hydrographs computed in each basin of the system were routed through Metro's interceptors using a model known as "NETWORK." NETWORK was a specially developed model using a kinematic wave approximation to the full equations of motion. The kinematic wave approximation does not fully account for backwater effects from pump stations and regulator gates, or any other downstream flow restriction. Thus, a complete description the system operation was not available (the actual impact of throttling back on the Interbay pump station could not be precisely simulated for example). Because flows from the north end of the system were not large, these were simulated as a constant value in development of the 1979 plan.

Table 1. History of Hydraulic Models Used for and by King County

Decade	Models		Brief Description of Capabilities
	Hydrologic (surface runoff and local system flows)	**Hydraulic** (Metro/KC trunks and interceptor flow)	
1970s	HYDRO		Used synthetic unit hydrograph method for runoff due to rainfall from 58 NSA* basins and 62 SSA** basins.
		NETWORK	Used kinematic wave approximation for simulating flow through Metro trunks and interceptors.
1980s	LCHYD		Used diurnal base flow and constant infiltration to generate hydrographs from separated areas. Linear rainfall/inflow relationship.
	HYDRO72		Used synthetic unit hydrograph method for 19 basins in NSA*.
	HYD72		Used synthetic unit hydrograph method for 62 basins in SSA**.
		LCPRE	Lagged the hydrographs from LCHYD to put into SACRO.
		SACRO	A mass balance model that simulated flow through the NSA. (Kept track of flow but didn't solve hydraulic equations for levels.)
		SSACRO	A mass balance model that simulated flow through the SSA.
		EBIPRE	Lagged the hydrographs from HYD72 to put into SSACRO.
		SACE	Estimated total system overflows based on rainfall only.
1990s — 2000s	RUNOFF		Kinematic wave simulation of runoff due to rainfall from > 400 basins. Variable inflow and infiltration based on rainfall and soil conditions. A physically based model.
		UNSTDY	A fully dynamic simulation of flow through King County trunks and interceptors. Computes flows, depths, and velocities in all pipes in the system. Simulates backwater effects, flow reversals, gravity waves, surcharges, etc. Simulates automatic operation of regulator and outfall gates and pump stations. Also, simulates Predictive Control, a computer program that controls the regulator gates to optimize the use of in-line storage. Used seven design storms in early 90s to estimate annual overflows. Moved to a continuous 11-year simulation to estimate annual averages in the late 90's.
2012 Program Update	RUNOFF	UNSTDY	The most recent calibrations of the hydrologic models were used. Calibrations were performed by KC staff, SPU staff, and by consultants hired by SPU.
	MOUSE (M_U)		
	EPA SWMM5		Hydraulic model had capabilities listed above. 32-year long-term simulations were performed to obtain 1-year volumes and peak flow rates.
	InfoWorks		

*NSA = Northern Service Area (North of the Ship Canal)
**SSA = Southern Service Area (South of the Ship Canal)

1986–1988 CSO Control Plan

In the modeling effort for the 1986–1988 CSO Control Plan, consultants used different programs to generate inflow hydrographs from the separated and combined portions of the service area. For the separated sewer area (upstream of the Lake City Regulator) the program LCHYD was used to generate flows from nine sub-basins. A diurnal base flow (e.g., showing two peaks within the same day) hydrograph was developed based on domestic/commercial and industrial populations. A linear relationship was assumed between rainfall and inflow, up to a maximum amount. Infiltration was assumed to be constant for the wet season. A maximum inflow value of 500 gallons per acre per day (gpad) was used for simulating future flows from currently non-sewered areas that were expected to develop and include sewers in the future.

The program LCPRE was used to take into account that peak flows do not occur at the same time in all parts of the system. This lag was incorporated into the simulation.

For the combined system, the program HYDRO72 was used to generate hydrographs from 19 basins in the Northern service Area (NSA). This was a modification of the HYDRO program used in the 1979 CSO control program. Several of the basins in the HYDRO simulation were combined for use in the HYDRO72 model. Furthermore, the length of simulation was increased from24 hours to 72 hours for HYDRO72, which allowed for longer storm events to be simulated.

The same basin parameters from the 1979 CSO Control Program effort were used in the 1986 effort. Despite concerns about the model, a decision was made to continue using the model for continuity with past planning. Five design storms were used to estimate annual CSO volumes and frequencies under existing (at that time) conditions and under future conditions.

The input hydrographs were then used as input to the SACRO (Seattle Area Central Routing Organization) simulation. SACRO simulated the routing of flow through the northern service area (NSA) of the wastewater system. It was designed to give reasonable estimates of the volume of flow through the NSA system. The flow from Interbay Pump Station was assumed to remain the same throughout the study period (1982–2030).

For the wet season, it was assumed that infiltration would remain the same as in the 1981-83 model calibration, at 1100 gpad. HYD72 (similar to HYDROT2) was used to generate synthetic unit hydrographs from 62 basins in the SSA. Seven design storms of varying length and intensities were used to estimate annual CSO frequencies and volumes for the SSA.

The Southern Service Area (SSA) large pipe flow was simulated using SSACRO (South Seattle Area Control Routing Organization). It was developed using primarily SACRO and some of NETWORK. It is based on level pool storage routing concepts and therefore does not accurately represent dynamic wave storage or routing. The program only calculated how the different input hydrographs travel through the system – combining sewer junctions, splitting at diversions, etc. It did not simulate the restriction of flows at the Interbay Pump Station due to flows at the West Point treatment plant exceeding its setpoint, which at that time was 325 million gallons per day.

SSACRO and SACRO basically added up all flows into a particular node (regulator, pump station, etc.), subtracted away that which could be hydraulically conveyed away from the node, and if anything was left, it was either stored or called an overflow. They are mass balance models, and do not compute water surface elevations in the collection system.

The program EBIPRE was developed to simplify and reduce the time involved in routing flows through the Elliott Bay Interceptor. It lagged inflow hydrographs and then combined them to be used in the routing model SSACRO. It also accounted for some of the City of Seattle CSOs and storage projects.

SACE (Seattle Area Combined Sewer Overflow Evaluator) was written to allow rapid testing of alternatives and to determine recurrence periods of overflows for design events. It calculated annual overflows for the wastewater system for the 1942-84 period. The SACE program simply assigned portions of each rainfall event to (l) system capacity; (2) system storage; and (3) rainfall that couldn't get into the sewer. The amount of available storage was increased during inter-event periods to reflect the draining of wastewater from storage. For each rainfall event, the wastewater entering the sewer that could not be contained in “system capacity” or “system storage” was considered to be CSO. There was no simulation of the flow as it proceeded toward the treatment plant.

CATAD Program Improvements—Predictive Control Program Begins

In 1986, a different approach was begun to model the West Point (combined) system, leaving behind the previous model. The effort was to support the development of an optimized real-time control program for the West Point collection system. The Predictive Control Program was to allow the Computer Augmented Treatment and Disposal System (CATAD) to automatically operate regulator gates and optimize in-line storage throughout the entire collection system to minimize CSOs.[1]

As part of this new approach, two new programs were developed to simulate flow through the West Point system. A kinematic wave runoff program was developed to simulate overland flow resulting from rainfall. Flow over both pervious and impervious areas that enters the sewer system was simulated. The West Point system was divided into over 400 basins to simulate this overland flow. This flow was then routed through a kinematic wave transport program, which effectively simulates the lagging and attenuation of flows through the local sewer pipes. The program also computes depths and velocities of flows in each pipe, and is a good approximation of actual conditions as long as there are no backwater effects or hydraulic transients (e.g., hydraulic phenomenon that are short in duration). Unlike previous programs used to model the wastewater, the runoff/transport program is a physically-based model that attempts to directly simulate the flow mechanics of the local sewer system. The program simulates a diurnal base

[1] Automatic control by CATAD was implemented in 1974. Predictive Control optimizes it.

domestic flow and a constant groundwater leakage. Inflow from rainfall induced hydrographs were simulated and input into the appropriate pipes for routing.

Over 70 flowmeters were installed to calibrate the runoff/transport model in the late 1980s.

The model UNSTDY was obtained in 1986 from Colorado State University to simulate the routing of runoff/transport flow hydrographs through the Metro/King County trunks and interceptor system. UNSTDY is a complex, fully dynamic simulation that computes flows, depths, and velocities in all pipes in the system. The full hydraulic equations are solved implicitly which enables it to simulate backwater effects, flow reversals, and gravity waves effectively. This sophistication was required to accurately simulate the in-line storage being utilized throughout the collection system. The model was enhanced to simulate the operation of the regulator gates and pump stations.

These two models can be envisioned as being like a tree or dendritical system with Runoff/Transport forming the leaves and outer branches and UNSYDY forming the inner branches and trunk.

UNSTDY was programmed to simulate the regulator system using local control (manual control), the existing Automatic Control, and the new Predictive Control. In early 1992 it was discovered that several of the level sensors (bubblers) were reading incorrectly, and probably had been since installation. The UNSTDY simulation was modified to be able to simulate control structures as they would have been operated if the sensors were reading incorrectly, as well as if they were reading correctly. This option (which simulates flow assuming errors in the levels sensors) is used when simulating conditions under “baseline” (1981 -83) conditions.

The runoff/transport program was enhanced in the early 1990s to include rainfall-induced infiltration into the sewer system. This infiltration can be the largest component of I/I during large storms in the separated portion of the County sewer system. This modification allows King County to simulate the flow from the northern part of the West Point service area much more accurately than had been possible previously.

The 1995 and 2000 CSO Control Plan Updates

For the 1995 CSO Control Update the same seven design storms used in the 1988 plan were used to estimate annual CSO volumes. For the 2000 CSO Control Update, 11-year continuous simulations were used to estimate CSO frequencies and volumes. As each flow transfer or CSO project is constructed, UNSTDY is modified to include that facility. For example, the Hanford/Lander Separation Project is included for simulations past 1990. The Carkeek flow transfer was included beginning in 1994. The Allentown Diversion was included in 1996. The Alki Flow transfer was included in 1998 as was the University CSO Project (Densmore Pump Station). The Denny Way CSO facility, the Harbor CSO transfer to the West Seattle Tunnel, and Henderson/Martin Luther King Way CSO facility are being simulated for 2005 and beyond.

SCADA Hardware and Software Upgrades

Computer hardware at West Point was been replaced in 2004–2005 for the offsite facilities. Software upgrades were also installed for operating the offsite facilities and for collecting, storing, and retrieving their data.

2012 CSO Control Program Review

Part of the work associated with the 2012 CSO Control Program Review has been recalibration of selected basins and associated pipe systems using DHI MOUSE/Mike Urban. This recalibration has been performed in some areas where King County has large CSOs to control. The MOUSE model (within the MIKE/Urban shell) was selected because MOUSE is being used for the entire separated portion of King County's service area. This model was selected during a process in 2001-2002 that evaluated several models for use in King County's Infiltration and Inflow (I/I) Program. The model has proved to be successful in simulating various kinds of inflow and infiltration responses in both combined and separated sewer systems and can provide a good match between model results and metering data. King County is in the process of standardizing the modeling of their entire service area using MOUSE. (DHI now only provides the MOUSE modeling engine within a software shell named MIKE Urban. Both names are used interchangeably in this document.)

In addition, Seattle Public Utilities (SPU) has been doing calibration of basin/pipe models in areas where they have CSO concerns. SPU has been moving from the Infoworks model to the EPA SWMM model for its work. Those areas SPU modeled sometimes overlap areas where the County has CSOs.

Time series used in the hydraulic model (UNSTDY) to estimate the CSO storage and flow requirements were generated by both the County and SPU for the areas that have been recalibrated. Those recalibrated time series replaced the Runoff/Transport time series in areas where the recalibrated hydrographs were available. Other areas continued to use the Runoff/Transport time series as input to the hydraulic model.

The overall model runs can be envisioned as being like a tree or dendritical system with portions of the leaves, outer and inner branches pruned back and MOUSE, Infoworks and SWMM model data grafted on in their place. However, UNSTDY is used to simulate the inner branches and trunk.

The models used to generate long-term hydrographs for the 2012 CSO Control Program Review for each basin group in the CSO service area are presented in Table 2. Figure 1 displays the hydrologic models that were in the 2012 CSO Control Program Review. All these models should be capable of simulating the hydrologic response of the basins, provided enough good quality flow data was available for calibration. Not all areas had equivalent data to work with, but the output from each respective model was considered the best available model data at this time.

Basins were recalibrated based on flow data from in-station meters and portable flow meters provided both by the County and SPU. SPU provided flow and level data at many locations. An important step in using this data was to perform QA/QC on the meter data. The SPU consultant provided QA/QC on all the flow data that they provided.

The County method for calibrating basins consisted of building up a basin and pipe model, providing a dry weather flow pattern based on dry weather meter data and then using a calibration tool called PEST to change selected basin parameters until model output was as close as possible to the meter data for selected storms. PEST is a Model-independent Parameter Estimation computer optimization code. The 5th edition of the code was used. After the best-fit parameters were generated using PEST, each modeler could adjust parameters to try to get a better overall fit. Effort was made such that both peak flows and volumes from the model matched the metered data and were not generally underestimated.

The results of these calibrations were reviewed by a team of modelers and further suggestions were provided for reworking the calibrations until they were judged to be acceptable based on review of hydrographs and the associated statistical data.

Table 2
Hydrologic Models used in 2012 CSO Control Program Review

Location	Hydrologic Model Used
8th Ave	MOUSE
Terminal 115	MOUSE
Harbor	MOUSE
Chelan	Runoff/Transport
S Michigan	MOUSE
Brandon	MOUSE
Hanford2	Runoff/Transport
Kingdome	MOUSE
King	MOUSE
Denny Local	MOUSE
Denny Lake Union	
Portage Bay	EPA SWMM5
Balance of Denny Lake Union	Runoff/Transport
Dexter	MOUSE (MU)
University	
Windermere	MOUSE (MU)
Green Lake/Densmore	MOUSE (MU)
Ravenna	MOUSE
North Union Bay	EPA SWMM5
Balance of University	Runoff/Transport
Montlake	
East Pine PS (Leschi)	EPA SWMM5
Madison Valley	InfoWorks/HSPF
Madison Park	EPA SWMM5
West Montlake	EPA SWMM5
Balance of Montlake	EPA SWMM5
Lander	Runoff/Transport
3rd Ave W	
Fremont	EPA SWMM5
Wallingford	EPA SWMM5

Balance of 3rd Ave W	Runoff/Transport
Rainier PS	MOUSE
Bayview	MOUSE
Hanford @ Rainier	MOUSE
11th Ave NW	Runoff/Transport
Alki (including Barton, Murray & 53rd PS)	Runoff/Transport
S Magnolia	Runoff/Transport
Ballard West (City Weirs)	SWMM
West Michigan	MOUSE
Balance of North Interceptor	Runoff/Transport
Henderson Pump Station	InfoWorks
Rainier@ Henderson	InfoWorks
Upstream of Matthews Park PS	Runoff/Transport

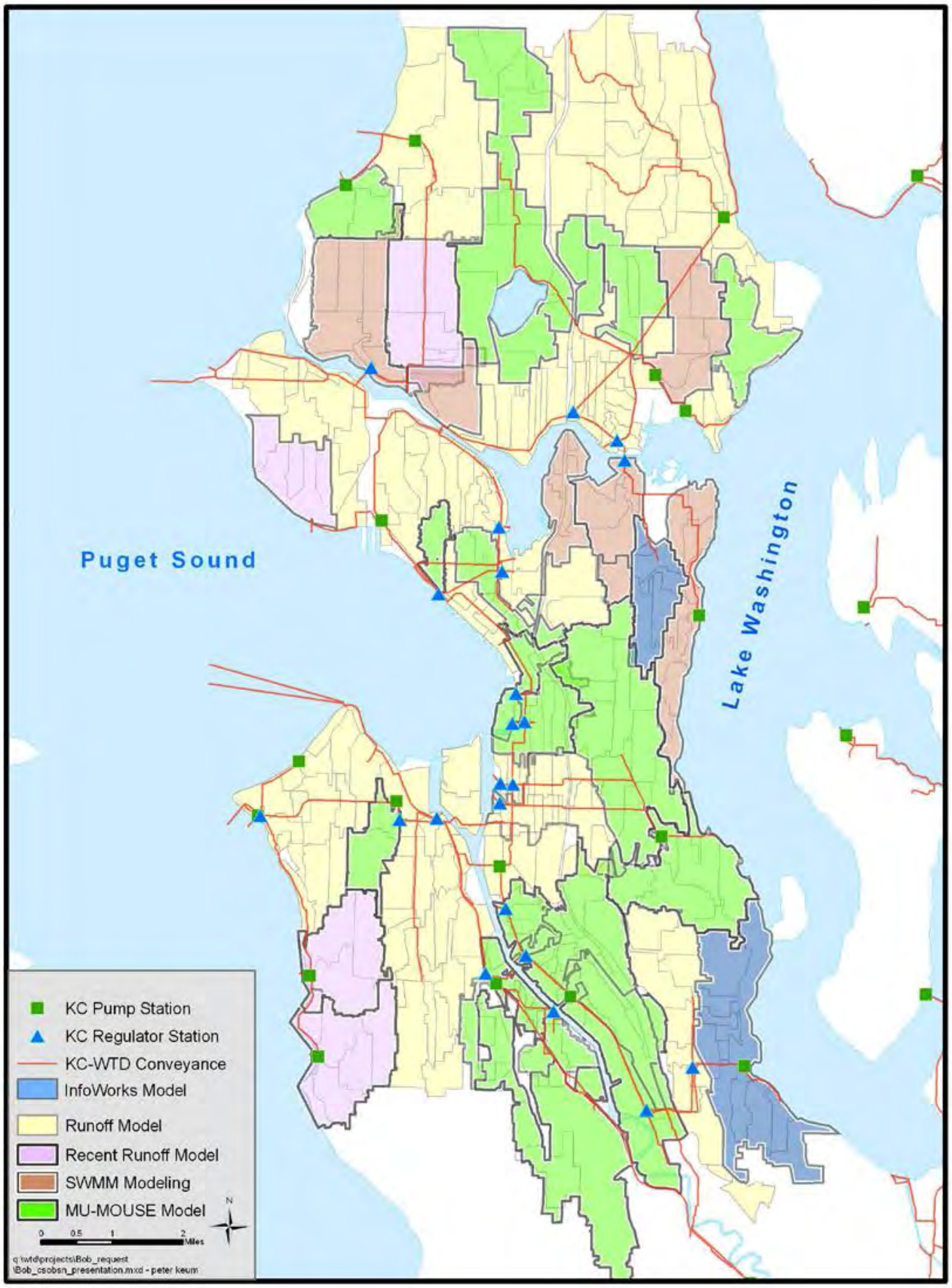

Figure 1 – Models used for hydrologic simulations for 2012 CSO Control Program Review

Once the basin calibrations were complete, a long term model run was performed and a downstream time series was generated to graft into the original models as noted above.

The County models were run using City of Seattle rain gauge information, with County QA/QC applied, to feed the basin models. The City models utilized similar data, but with City processing applied. This data was available and formed the long-term model period from January 1st, 1978 to January 1st, 2010. That is a 32-year time period. The hydrologic model runs started in 1977, using SeaTac data in order to simulate appropriate ground moisture conditions at the start of 1978. The UNSTDY hydraulic model run began a few days prior to 1978 and extended into 2010 to allow the model to initialize and stabilize at the start and to terminate at the end outside of this 32-year period. CSO statistics were generated for the period noted above.

Once the 32-year simulations were performed, statistics were generated to obtain the 1-year peak CSO volumes and the 1-year peak flow rates for use in the 2012 CSO Control Program Review.

Appendix B.2

East Duwamish Treatment Facility Consolidation – Upstream Diversions at Pump Stations to Reduce or Control Downstream CSOs

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MEMORANDUM (Memo 1, Version 1.1)

Date: **September 1, 2010**

From: **Bruce Crawford**

To: **Karen Huber**

Subject: **Consolidation of EBI CSO's 1 – Pump Station Diversions**

This memo sets out to answer the question, "if we divert flow at East Marginal and Duwamish pump stations, how much can we reduce downstream CSO's?

Data and Method

The data used for this analysis was from the May 2010 (2010A) run set. The method used was to add time series of overflows downstream of a diversion location, then subtract the diverted (pumped) flow time series, setting any negative numbers to zero. The result was the ideal, best case, remaining CSO time series.

Note that this method does not account for flow time differences between locations. The more spread out the locations are, the more uncertainty there is that flow peaks will coincide at diversion and CSO locations and increases the difficulty in anticipating when diversion will be needed. That is why this analysis should be viewed as a "best case" that may not be fully obtainable.

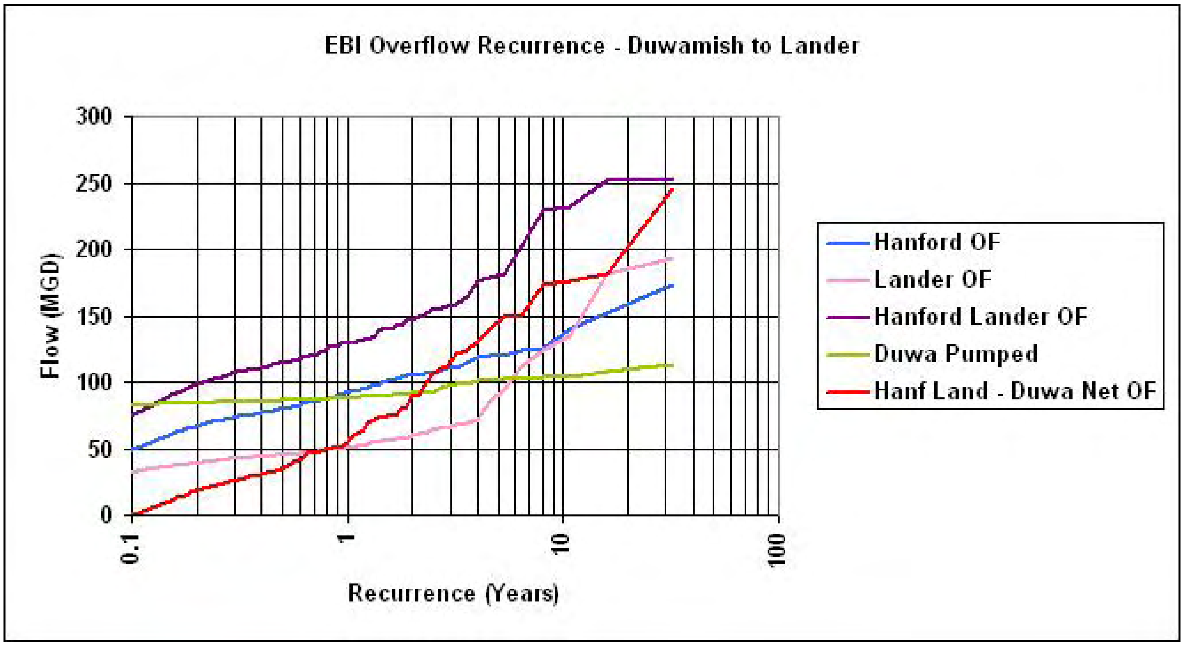
Diversion of flow far upstream of a CSO location would need to anticipate a likely CSO situation a length of time equivalent to the travel time between the diversion and the CSO locations. This need to anticipate would also result in more diversion with a lower efficiency expressed either as diversion when not needed or lack of diversion with a resultant overflow.

All the time series were analyzed with peaks found, ranked and recurrence curves generated. Those recurrence curves are provided in graphs which appear below.

Diversion at Duwamish PS

Two scenarios were analyzed for diversion of flow at Duwamish PS. The first scenario was to look at how much the Hanford and Lander CSO's could be reduced. The second scenario was to look at how much the Hanford, Lander, Kingdome and King (HLKK) CSO's could be reduced.

The following graph provides the recurrence curves associated with Duwamish PS and the Hanford and Lander CSO's.



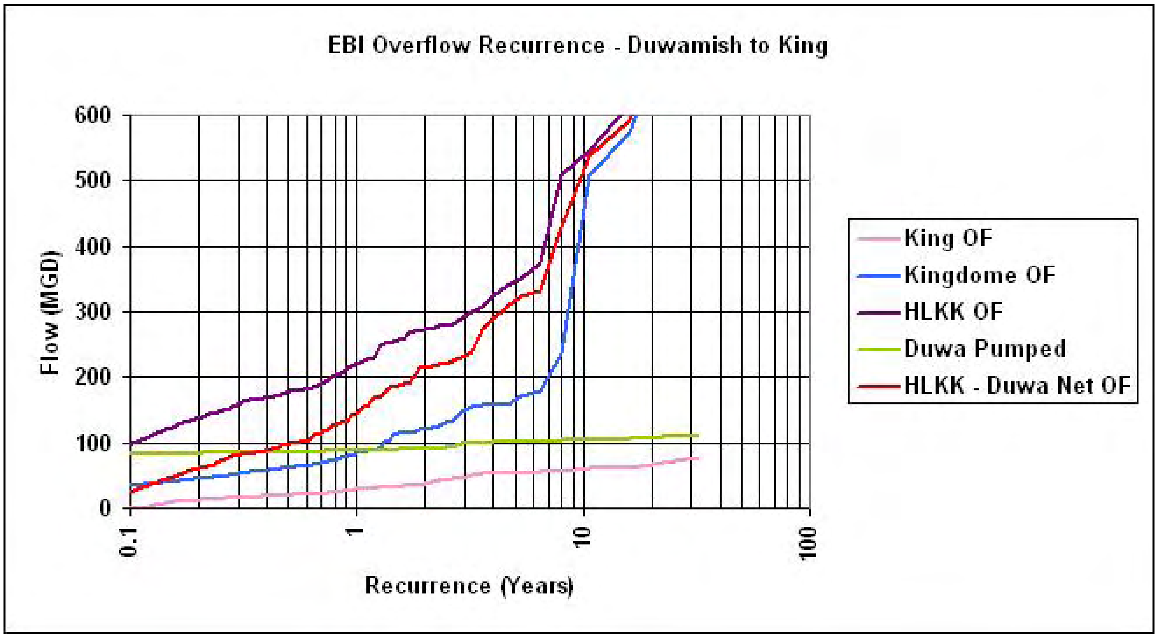
Graph 1 – Duwamish PS Diversion to Reduce Hanford and Lander CSO's

The curves are as follows:

Hanford – blue, one year overflow 92 MGD, no flow extraction at Duwamish PS
Lander – pink, one year overflow 50 MGD, no flow extraction at Duwamish PS
Hanford and Lander – purple, one year overflow 129 MGD, no flow extraction at Duwamish PS
Duwamish – light green, one year pumping rate 88 MGD
Remaining CSO from Hanford and Lander – red, one year overflow 55 MGD, with flow extraction at Duwamish PS

The fact that the Hanford plus Lander CSO time series recurrence curve is less than the sum of the individual time series curves indicates that the peaks are offset in time somewhat between the two CSO locations. Subtracting the Duwamish pumped flow time series results in a remaining one year CSO rate of 55 MGD. This is higher than if the one year Duwamish flow were subtracted from the one year CSO from the added Hanford and Lander time series. That indicates a bit of a time offset between Duwamish peak pumping rate and the CSO peak flow rate even without hydrodynamic modeling of this scenario.

The following graph provides recurrence curves from the second scenario of using Duwamish pump station diversion to offset overflows at Hanford, Lander, Kingdome and King (HLKK).



Graph 2 – Duwamish PS Diversion to Reduce HLKK CSO's

Some of the curves shown in graph 1 are not repeated in this graph. The curves are as follows:

Kingdome – blue, one year overflow 29 MGD, no flow extraction at Duwamish PS
King – pink, one year overflow 85 MGD, no flow extraction at Duwamish PS
HLKK – purple, summed time series, one year overflow 221 MGD, no flow extraction at Duwamish PS
Duwamish – light green, one year pumping rate 88 MGD
Remaining CSO at the four HLKK trunks – red, one year overflow 144 MGD, with flow extraction at Duwamish PS

Looking at the graph, there is one obvious problem which does not impact the one year flow rates. Kingdome shows an extremely high set of flow rates above the 6.4 year flow, indicating that there were 4 incidents of likely instability in the 32 year run.

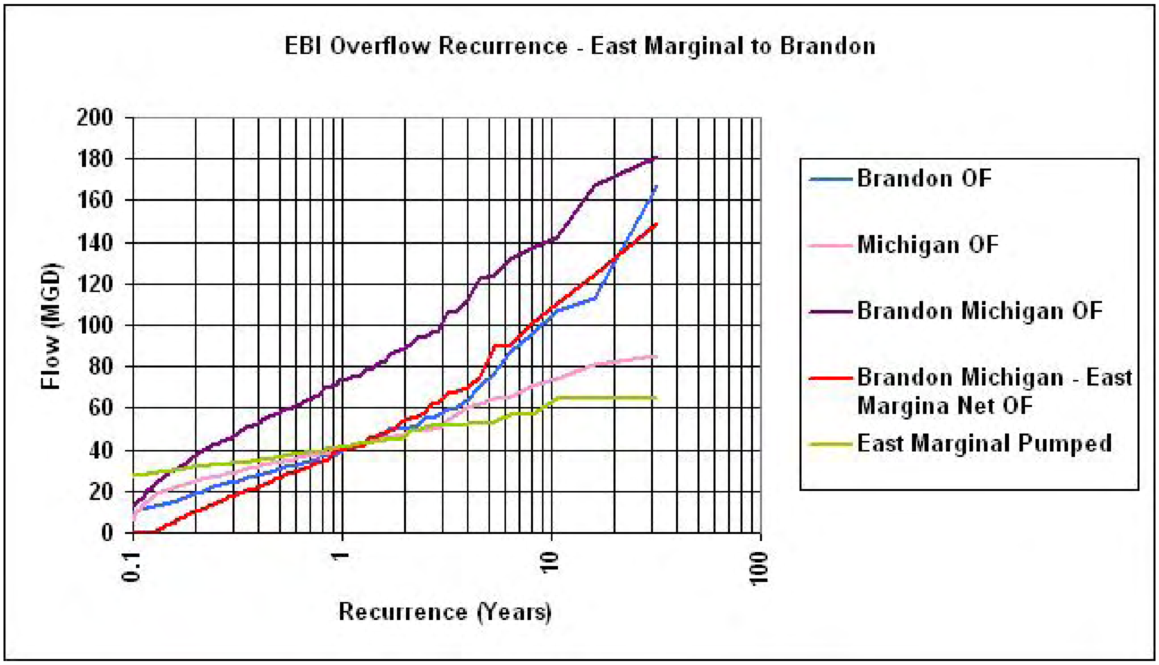
The added overflow time series have a one year flow of 221 MGD, which is almost a 14% reduction from what would be obtained by adding the one year flow rates from individual locations instead of the adding time series and analyzing the result.

The remaining CSO of 144 MGD shows a reduction similar to that experienced with the Hanford Lander scenario. However, given the increased distance between the diversion and most downstream CSO locations, the anticipation time required would be increased.

Since the flow rate at Duwamish does not completely compensate for CSO's at Hanford and Lander, it does not seem that considering that diversion with respect to the further downstream CSO's at Kingdome and King has any further purpose.

Diversion at East Marginal PS

Only one scenario was considered at East Marginal pump station. That scenario is diversion of flow from East Marginal pump station to compensate for downstream CSO's at Michigan and Brandon regulators. The following graph provides the recurrence curves associated with this scenario.



Graph 3 – East Marginal PS Diversion to Reduce Michigan and Brandon CSO's

The curves are as follows:

Brandon – blue, one year overflow 39 MGD, no flow extraction at East Marginal PS
Michigan – pink, one year overflow 40 MGD, no flow extraction at East Marginal PS
Brandon and Michigan – purple, one year overflow 73 MGD
East Marginal – light green, one year pumping rate 41 MGD
Remaining CSO at Brandon and Michigan – red, one year overflow 39 MGD, with flow extraction at East Marginal PS

The fact that the Brandon plus Michigan CSO time series is less than the sum of the individual time series at those locations indicates that the peaks are offset in time somewhat between the two CSO locations. Subtracting the East Marginal pumped flow time series results in a remaining one year CSO rate of 39 MGD. This is higher than if the one year East Marginal flow were subtracted from the one year CSO from the added Brandon and Michigan time series. That indicates a bit of a time offset between East Marginal peak pumping rate and the CSO peak flow rate even without hydrodynamic modeling of this scenario.

Travel Times

The travel time in the EBI between a diversion location and a CSO location indicates how much the algorithm diverting flow would need to anticipate a CSO to be successful. The longer this time is, the less efficient any algorithm is likely to be. Inefficiency will show up as either diversion when it is not required or lack of diversion when it is required, with a corresponding overflow.

A quick approximation of the EBI travel time can be gained using Manning's Equation for a full flow condition. The EBI travel times are as follows:

Duwamish to Hanford, 27 minutes
Hanford to Lander, 10 minutes
Lander to Kingdome, 34 minutes
Kingdome to King, 12 minutes

East Marginal to Michigan, 25 minutes
Michigan to Brandon, 25 minutes

These times show that the least challenging scenario, from a control viewpoint, would be to divert pump station flow only to attempt reduction of the CSO immediately downstream of each pump station. That would be, reduce Michigan overflows with East Marginal pumped diversion and reduce Hanford overflows with Duwamish pumped diversion.

Attempting to divert for further downstream locations such as King, Kingdome and Brandon would introduce greater difficulties due to the increased travel time. The increased travel time would increase the time for which flows would need to be anticipated. That would introduce greater inefficiencies in diversion as noted above.

Summary

It would be possible to divert flow from the EBI pump stations to reduce some of the downstream overflows. This would utilize existing pumping capacity to lift flow into treatment facilities. The limitations to this method of diverting flow include: existing pump capacity, differential timing of peak flows, and inefficiencies that would be introduced when attempting to anticipate the need to divert flow. These limitations would tend to limit this method to favor reducing CSO's only at locations immediately downstream of the pump stations.

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Appendix B.3

East Duwamish Treatment Facility Consolidation – Upstream Diversions along the Elliott Bay Interceptor to Reduce or Control Downstream CSOs

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MEMORANDUM (Memo 2, version 1.0)

Date: **July 16, 2010**

From: **Bruce Crawford**

To: **Karen Huber**

Subject: **Consolidation of EBI CSO's 2 – EBI Diversions**

This memo sets out to answer the question, "if we divert flow from the EBI at given locations, how much can we reduce downstream CSO's?

Data and Method

The data used for this analysis was from the May 2010 (2010A) run set. The method used was to add time series of overflows downstream of a diversion location, then subtract the EBI flow time series at an upstream location, setting any negative numbers to zero. The result was the ideal, best case, remaining CSO time series.

Note that this method does not account for flow time differences between locations. The more spread out the locations are, the more uncertainty there is that flow peaks will coincide at diversion and CSO locations and increases the difficulty in anticipating when diversion will be needed. That is why this analysis should be viewed as a "best case" that may not be fully attainable.

Diversion of flow far upstream of a CSO location would need to anticipate a likely CSO situation a length of time equivalent to the travel time between the diversion and the CSO locations. This need to anticipate would also result in more diversion with a lower efficiency expressed either as diversion when not needed or lack of diversion with a resultant overflow.

Note that the EBI time series were available as flow immediately downstream of trunk connection points. For instance, an EBI at Hanford flow would be the EBI flow in the model immediately downstream of the Hanford trunk connection. In a one year storm event, the regulator gate would likely be closed and flow from the trunk would be minimal. However, the EBI flow in smaller events may include some flow from the adjacent trunk.

All the time series were analyzed with peaks found, and ranked, and recurrence curves generated. Those recurrence curves are provided in graphs which appear below.

Scenarios and Results

The following scenarios for diversion of flow in the EBI to reduce downstream overflows were considered:

Diversion at Michigan to reduce Brandon CSO – Subtract the EBI flow downstream of Michigan from the Brandon overflow time series to obtain the remaining CSO time series.

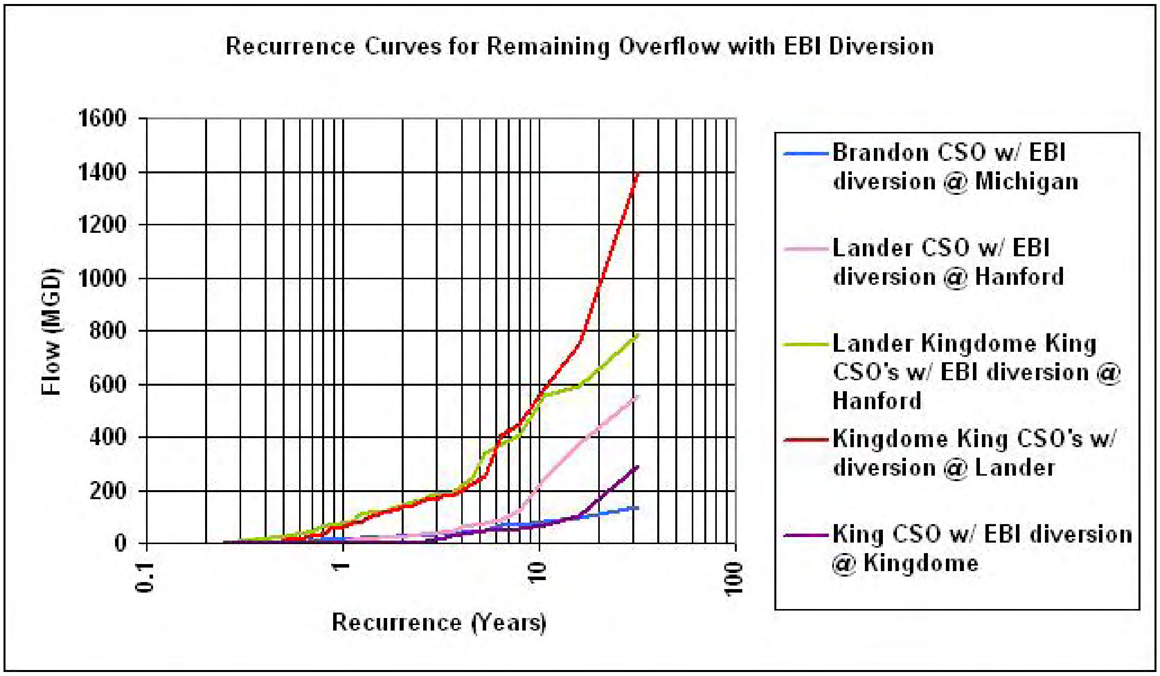
Diversion at Hanford to reduce Lander CSO – Subtract EBI flow downstream of Hanford from the Lander overflow time series to obtain the remaining CSO time series.

Diversion at Hanford to reduce Lander, Kingdome and King CSO's – Add the Lander, Kingdome and King overflow time series together and then subtract the EBI flow downstream of Hanford to obtain the remaining CSO time series.

Diversion at Lander to reduce Kingdome and King CSO's – Add the Kingdome and King overflow time series together and then subtract the EBI flow downstream of Lander to obtain the remaining CSO time series.

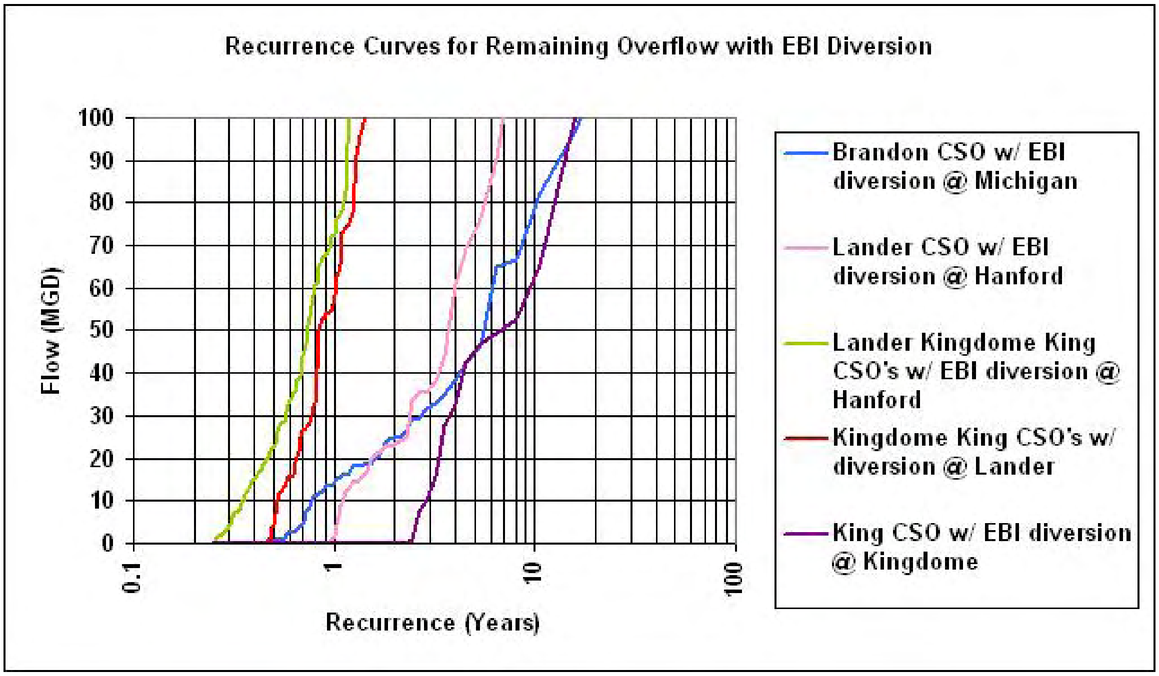
Diversion at Kingdome to reduce King CSO – Subtract EBI flow downstream of Kingdome from the King overflow time series to obtain the remaining CSO time series.

The calculations for the scenarios noted above were performed and then the remaining CSO time series were analyzed for event recurrence and a graph was produced, as shown below.



Graph 1 – Recurrence Curves for Remaining CSO's with upstream EBI diversions

In order to make the results at a one year event easier to see, the above graph was zoomed into the 0 to 100 MGD range as shown below.



Graph 2 – Recurrence Curves for Remaining CSO's with upstream EBI diversions, Zoomed in

The graph above shows the remaining one year CSO flow rates for the scenarios

Brandon CSO w/ EBI diversion at Michigan – blue, 14 MGD
Lander CSO w/ EBI diversion at Hanford – pink, 2 MGD
Lander, Kingdome and King CSO's w/ EBI diversion at Hanford – light green, 73 MGD
Kingdome and King CSO's w/ EBI diversion at Lander – red, 58 MGD
King CSO Diversion w/ EBI diversion at Kingdome – purple, zero MGD, no one year overflow

A summary table of the reduced overflow rates along with the original overflow rates follows.

Peak 1 Year Overflow Rates (MGD)

Locations Reduced	Existing	EBI Diversion Location	Remaining
Brandon	39	Michigan	14
Lander	50	Hanford	2
Lander, Kingdome, King*	149	Hanford	73
Kingdome, King*	105	Lander	58
King	29	Kingdome	0

* recurrence of sum of overflow time series

The most evident case of a workable flow diversion is the diversion at Kingdome to control King. This would indicate a treatment plant placed at Kingdome that diverted flow from the EBI could also be used to control the King CSO to a one year level of control.

Another lesson of this scenario is useful for the case of backflowing the EBI to route flow to an "upstream" treatment plant. If a gate were placed downstream of Kingdome to limit flow continuing to King, the King CSO could be controlled. This helps define the downstream design required for backflowing the EBI for centralized treatment in the Hanford/Lander area and will be used in the analysis and memo on that subject.

There is a scenario that almost controls the one year overflow at the downstream location. It is to divert EBI flow at Hanford to control Lander. The Hanford/Lander plant combination is not a scenario that will be covered in the next memo on centralized treatment. However, there is enough information here to indicate that given a complete diversion of the EBI at Hanford, along with some likely backflow in the EBI, the Lander CSO could likely be controlled. This would be one of at least a few flow routing options available to such a plant.

The scenarios of diversions at Hanford and Lander are clearly insufficient to control CSO's downstream to Kingdome and King. This indicates that a consolidated Hanford/Lander/Kingdome/King (HLKK) treatment plant would require backflow along the EBI from Kingdome, as noted above, if the flow were to be conveyed to the plant via the EBI.

A scenario with a similar outcome is the diversion of EBI flow at Michigan to control Brandon. There is a sufficient remaining one year overflow at Brandon in that scenario that it becomes evident that a consolidated Michigan/Brandon (MB) plant would require backflow in the EBI from Brandon to Michigan, if plant inflow were to be routed via the EBI. Gate control may be required at Brandon to shift the additional 14 MGD southward in the EBI to a Michigan area plant.

Summary

The results of the analysis do not show a large number of cases where simple diversion from the EBI will achieve downstream CSO control. However, the analysis does indicate how control of backflow along the EBI could be configured at the downstream terminus to allow for plant consolidation. That will be useful information for the next analysis and memo.

Appendix B.4

East Duwamish Treatment Facility Consolidation – Upstream Diversions and Backflowing the Elliott Bay Interceptor to Control Downstream CSOs

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Memorandum

Date: **October 7, 2010** (memo 3, version 1.4)

From: **Bruce Crawford**

To: **Karen Huber**

Subject: **Consolidation of EBI CSO's 3 – EBI Backflow**

The prior memos in this series covered diverting flow at pump stations to control CSO's further down the EBI (memo 1) and diversion of flow from the EBI to control CSO's further down the EBI (memo 2). This memo covers diverting flow from the EBI and inducing back flow along the EBI to control CSO's further down the EBI.

Memo 2 considered diversion of flow from the EBI and found that downstream CSO's could only be minimally controlled, limiting the opportunities for treatment plant consolidation using that method. This memo will extend that method to include back flow in the EBI from downstream CSO's to consolidate the treatment processes down to two plants.

Note that there are system schematics provided in a separate file that you may refer to while reading this memo.

Excess flows that are currently overflowed would be routed instead to the EBI where they are conveyed to a diversion point, leading to a treatment plant. Some of the flow routed from the EBI diversion point to the treatment plant would actually be upstream flow in the EBI (similar to memo 2). This would reduce the amount of back flow required.

Another way of reducing the amount of flow into the EBI would be to site each plant at the most upstream CSO location served, and route the flow from that trunk directly to the plant. This happens to work quite well since the upstream CSO locations have high overflow rates. Those flows, when added to the existing flow, would exceed the EBI capacity.

The EBI CSO locations can be consolidated into two groups for treatment, upstream and downstream of the Duwamish pump station. The downstream group of CSO's includes

Hanford, Lander, Kingdome and King (HLKK). The upstream group includes Michigan and Brandon (MB).

While it is possible to look at routing excess flow for each group to one diversion location on the EBI, it is not possible to route excess flow for both groups to one EBI diversion location. This means that there must be two EBI flow diversion points at a minimum. There could either be a treatment plant associated with each EBI diversion point, or conveyance pipes between the two EBI diversion locations and a single treatment plant.

For this analysis, diversion points for plants have been assumed to be located at upstream trunks with major CSO flows (Hanford and Michigan). As was noted above, this ensures flow from those trunks can be routed directly to the treatment plant without flowing into the EBI. The additional flow from those trunks would exceed the conveyance capacity if routed into the EBI.

Downstream Conditions

One of the major issues to consider is what the downstream condition is in the EBI as flow is routed to a diversion point.

In each CSO group discussed above, some of the upstream flow from the EBI will be diverted to offset captured overflow at downstream locations. An equal quantity of captured overflow at downstream locations can then flow downstream out of the group area.

Downstream captured overflow up to the amount of upstream EBI diverted flow can be allowed to flow downstream out of the group area, but any additional downstream captured overflow must be routed via backflow in the EBI to the point at which flow is diverted to treatment.

The upstream diverted flow does not exactly equal the sum of one year captured overflows at downstream CSO locations. In effect, there is one downstream location in each group at which some captured overflow may be routed downstream in the EBI in a normal direction and the remainder must be routed upstream to the treatment facility.

Another factor that adds complexity is that the water surface one might typically encounter at that downstream location in a one year event will tend to vary. If the total inflow to the EBI exceeds the pumping capacity in use at Interbay pump station and Elliott West CSO facility and the tide is sufficiently high, the EBI level will tend to be somewhat above the tide level.

A higher downstream water level will tend to raise the entire Hydraulic Grade Line (HGL) along the EBI all the way up to the upstream limit of the each CSO group at either Duwamish or East Marginal pump station discharge locations. This makes backflow along the EBI from downstream CSO locations to the plant diversion location easier as the greater depth increases the flow area cross section and thereby reduces velocity and the head loss. It does, however, make surface flooding at the upstream pump station discharge a higher risk.

A lower downstream water level will tend to lower the HGL along the EBI, at least up to the plant diversion location. This would make backflow along the EBI from downstream CSO locations to the plant diversion location more difficult as the decreased depth decreases the flow area cross section, increasing velocity and the head loss. There should be a downstream level, below which, sufficient back flow to the treatment plant diversion can not be sustained.

A gate in the EBI at the farthest downstream CSO for which captured flow is to be routed to the plant diversion would help to maintain the backflow and the HGL within acceptable limits independent of conditions further downstream in the EBI. Note that some captured overflow at that downstream CSO will need to be injected into the EBI upstream of the downstream gate so it can backflow to the plant diversion and some of that flow will need to be injected into the EBI downstream of the gate in the EBI so it can follow a normal path towards Interbay and West Point.

This means that the downstream CSO location with captured overflow split between the plant and the downstream EBI may need a triple gate assembly. In such a layout, one gate would be in the EBI and two gates would route flow from the trunk to either side of the EBI gate.

The flows and the flow split routed to CSO treatment could be expected to vary during each storm and from storm to storm. More extensive modeling of this scenario would reveal whether the flows vary sufficiently to require splitting flow at different locations during different storms. If there is a large variation, the placement of the downstream EBI gate should be at the furthest downstream location for which flow may need to be routed to CSO treatment. The EBI gate and trunk gates would then be modulated to achieve the desired flow split.

The downstream EBI gate would also aid in the transition from the normal EBI flow to backflow to the treatment plant diversion during a storm event, and then back to normal flow afterwards.

Note that in addition to the downstream gate, an emergency weir and outfall pipe from the EBI just upstream of a gate may be required to ensure a pathway for emergency relief should the gate fail in a closed position or should a surge occur due to its operation.

For the purposes of this analysis two HGL conditions will be studied.

1. The minimum downstream level at which back flow towards the treatment plant diversion point is possible.
2. The maximum downstream level without probable surface flooding at the upstream pump station discharge point.

Hanford Lander Kingdome King Plant (HLKK)

A simplified steady state MOUSE model was developed to look at an approximate one year hydraulic grade line along the EBI with inflows from regulators with captured overflows to be conveyed via the EBI to the diversion point and treatment plant. One year overflows were added to existing one year interceptor flows and flow was withdrawn for a plant in the Hanford area.

The model included the EBI from Duwamish pump station down to Kingdome regulator. It did not extend to King because overflow at that location could be traded for extra flow to treatment from the Duwamish pump station. If this option is pursued, a more detailed model extending to Interbay pump station will need to be run to ensure levels and flows downstream of this area are kept within current limits or are modified to benefit operation at Elliott West, Interbay and the Denny regulators.

The flow withdrawn from the EBI to treatment at Hanford was equal to the summed one year overflows from King, Kingdome and Lander. Hanford trunk overflow was assumed to be routed directly to the plant in order to limit the difficulty of achieving a workable hydraulic grade line. The Hanford one year overflow is roughly equivalent to the EBI Mannings capacity and, if routed to the EBI, would severely limit use of the EBI to convey any other flows. So, a direct connection of the Hanford trunk to the plant allowed for conveying other flows in the EBI without undue losses.

The one year overflow rates for the CSO locations served by this plant follow.

King	29 MGD
Kingdome	85 MGD
Lander	50 MGD
Hanford	92 MGD

The combined time series from all the locations have a one year flow of 221 MGD. This is lower than the sum of the individual one year flows because the peak flows do not all occur at the same time. While this lower flow rate could be used to size the inflow to a plant, the individual flows would be the additional flow rates to convey into and through the EBI. So, those individual flows were used for a model run to investigate the hydraulic grade line.

Note that the one year pumped flow at Duwamish is 88 MGD and the one year pumped flow at West Seattle is 19 MGD. Both these flows can be drawn from the EBI at Hanford to substitute for downstream overflows that are captured and routed into the EBI.

The existing downstream one year conditions at Kingdome were determined to be a level of 106.68 and an interceptor flow, southward from the regulator, of 121 MGD. This flow is rather high for the EBI. It is likely to be a short lived peak flow that may not occur at the same time as the peak captured overflows. However, for this initial analysis, all peak flows will be assumed to occur at the same time.

We may find that it may be useful to limit flow out of the service area for this consolidated treatment plant in order to maintain beneficial conditions for the operation of the Elliott West CSO treatment plant. At a minimum, we would not want flow out of this service area to the Elliott West service area to exceed its current rates and at a maximum we may want to further offload peaks from Elliott West from the EBI to improve its solids capture balance.

In any case, if this option of routing flow to a consolidated CSO treatment plant is pursued, a model extending down to Interbay pump station should be used with a long term modeling period to assess and mitigate downstream impacts to the Elliott West facility.

As was indicated in the section on downstream conditions, the maximum and minimum workable downstream water levels were found by running the model and are shown on the profile which follows.

The relatively high downstream flow in the EBI of 121 MGD requires an additional 14 MGD entering the EBI between Duwamish and Kingdome in addition to the flow from the Duwamish and West Seattle pump stations. The regulators typically should not be contributing flows to the EBI under existing conditions as all regulator gates should be shut during a one year storm event, but there are also additional unregulated flows from two basins into the EBI.

The additional flow of 14 MGD was proportioned to the two basins known to directly connect to the EBI based on the impervious area connected proportions in the Runoff model. The proportions of 35% for basin 199, entering approximately at Lander and 65% for basin 202, entering approximately at the West Seattle force main discharge, were used to divide this flow. So, 4.9 MGD was added to the inflow at Lander and 9.1 MGD was added to the inflow at West Seattle.

When the flows from Duwamish and West Seattle are added to the local flows, the total slightly exceeds the sum of captured overflows at King and Kingdome. This means that King and Kingdome captured overflows can be completely substituted with upstream flows in the EBI sent to the treatment plant. When that flow is removed from the EBI, it makes room for the King and Kingdome overflow rates to be routed into the EBI.

Hence, 7 MGD can flow from Lander towards Kingdome. However, this depends on the local basin flows being sufficiently large and occurring at the same time as the peak captured overflows. It would be wise to consider being able to route some flow from Kingdome back to Hanford, should local flows prove insufficient to completely offset King and Kingdome. A more detailed long term analysis would be useful, as would be calibration of the directly connected EBI basins.

The captured overflow of 50 MGD at Lander must flow back to the Hanford treatment plant diversion point through the EBI.

The plant flow drawn from the EBI at Hanford was set equal to the sum of the captured one year overflows at King (29 MGD), Kingdome (85 MGD) and Lander (50 MGD), for a total of 164 MGD.

EBI Inflows and Outflows

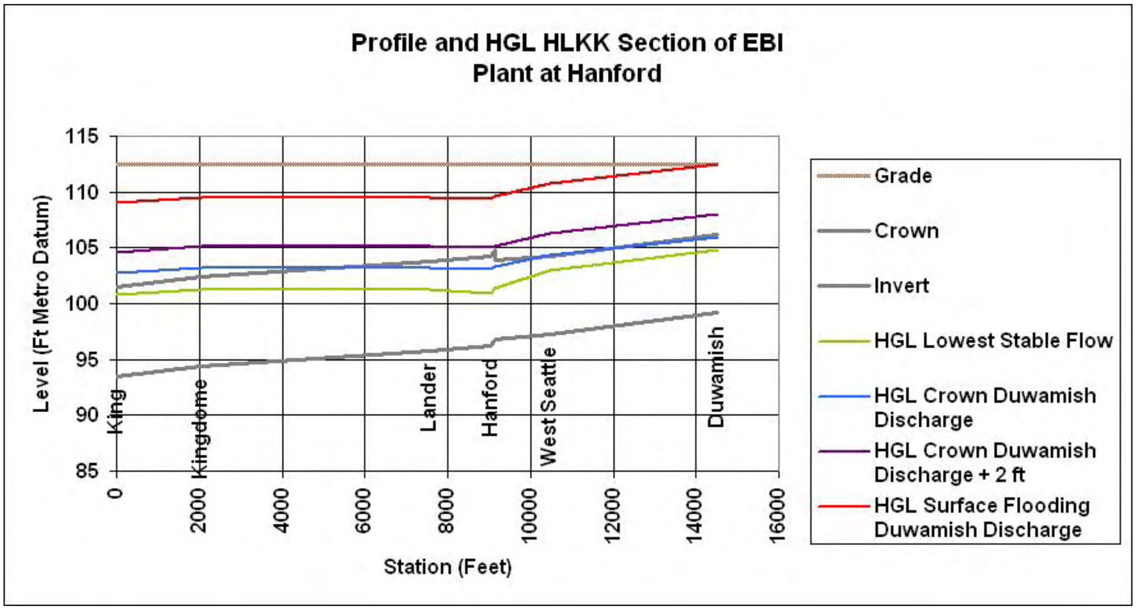
Duwamish	88 MGD in
West Seattle	19 MGD in plus 9 MGD local in
Hanford	164 MGD out to plant
Lander	50 MGD in plus 5 MGD local in
Kingdome	85 MGD in
King	29 MGD in
EBI to Interbay	121 MGD out

Flows in Sections of the EBI

Duwamish to West Seattle	88 MGD
West Seattle to Hanford	116 MGD
Hanford to Lander	-48 MGD (backflow)
Lander to Kingdome	7 MGD
Kingdome to King	92 MGD

As was noted above, for this set of model runs these peak flows are assumed to occur at the same time in a steady state situation. Actual conditions will vary considerably from storm to storm and there may be backflow from Kingdome to Hanford in some events and we may elect to limit flow leaving the service area and continuing to the Elliott West service area.

The profile from this run follows.



Graph 1 – HLKK Profile and Hydraulic Grade Line

The lowest level at which flow stabilized at the desired rates is the lowest water surface or hydraulic grade line shown. Three high levels were considered with respect to their impact at the Duwamish discharge structure.

1. The level at the crown of the pipe, maximum non-surcharged flow
2. The level two feet above the crown of the pipe, the point at which prior modeling for Duwamish showed throttling was necessary
3. The level at the ground surface, when surface flooding would actually start

This profile shows the hydraulic grade line (HGL), or water surface, from Lander to Kingdome is only slightly sloped since the flow is limited. If flow were to be routed back from Kingdome to Hanford, the slope would reverse and may steepen.

The HGL from Duwamish to West Seattle matches the pipe slope. Closer to Hanford the HGL slope increases slightly from Lander to Hanford due to is steep due to the added flows at Lander. The HGL slope from the West Seattle force main discharge to Hanford is steeper due to the West Seattle force main discharge and local basin inflow.

The highest water surface along this profile remains at the Duwamish pump station discharge structure. So, if levels were to rise and become excessive, surface flooding at Duwamish discharge would likely be the first indication of excessive HGL elevations.

However, with the use of a downstream gate in the EBI, it is more likely that levels in the section of the EBI draining to the treatment plant could be controlled at a level close to the lowest HGL shown, and that the level at the upstream Duwamish pump station discharge could be controlled so that pumping is maximized without the danger of surface flooding at the discharge structure. Otherwise, the level at the Duwamish pump station discharge may be more influenced by downstream events and the tide level.

If a gate were used to isolate this section of the EBI from downstream influences, it would tend to allow Duwamish pump station to continue pumping without throttling due to high discharge levels. So Duwamish pump station overflows may also be more reliably controlled by the downstream HGL control a downstream EBI gate offers.

One important thing to note is that the HGL is for a steady state situation. The transition from a normal HGL with flow all routed to Kingdome and downstream to the HGL shown above could require more control to ensure captured overflows are actually routed back to the plant and do not adversely impact Elliott West.

A gate in the EBI just downstream of Lander or more likely Kingdome, as noted above, would also likely help ensure protection of facilities downstream of this section from excessive flows that may develop as the HGL transitions and the treatment plant is started. In addition, as noted above, such a gate would tend to keep the water level this section of the EBI lower during high tide situations.

However, the profile above also shows that the below grade vertical space above the EBI for installation of a gate would be tight and may not allow for construction using a typical gate that closes from the top down.

Hanford Lander Kingdome (HLK)

The next subgroup to consider is Hanford, Lander and Kingdome, assuming that King is dealt with using a storage project of its own. The one year flow from Duwamish pump station (88 MGD), West Seattle pump station (19 MGD) and local basin flows (14 MGD) easily exceed the Kingdome one year flow of 85 MGD, assuming Lander flow is still routed via the EBI to the Hanford CSO treatment plant diversion point.

This means that it should be possible to divert sufficient flow from the EBI at Hanford to allow all captured overflow to be put into the EBI at Kingdome up to the one year overflow rate. This would mean there would be a storage tank built at King, an upsized regulator gate at Kingdome to put captured overflow into the EBI, and a gate to remove flow from the EBI at Hanford. A downstream gate in the EBI just downstream of Lander or Kingdome could be considered in more detailed modeling. It may not be as necessary for developing the proper flow routing, but would still have benefits for Duwamish pump station operation.

Since this involves less flow than the HLKK option, does not involve King, does not require backflow and might not require a downstream gate, it would be simpler to control.

Lander Options

The existing intertie pipe is insufficient to convey the total Lander one year overflow, 50 MGD, to Hanford, or to convey the Hanford one year overflow of 92 MGD to Lander. The intertie capacity is limited by the existing Lander overflow weir elevation and the water surface level in the Hanford Trunk associated with the Hanford and Lander flow in that trunk. A simplified DHI MOUSE model showed intertie capacity topping out at around 30 MGD from Lander to Hanford without overflowing the Lander weir with the one year flow rate in the Hanford Trunk to diversion point west of the intertie. A diversion point east of the intertie might increase this capacity somewhat. However, it might also make routing the diversion pipe to treatment more complex.

At least a portion of the captured overflow from Lander trunk must be conveyed to the EBI and then drawn out at Hanford, or alternatively, a pipe from Lander trunk to the treatment plant must be constructed. It might be easier from a control viewpoint to convey all the Lander flow via the EBI to Hanford rather than to split the flow between the intertie and the EBI. However, if the Lander trunk level is high enough, some flow through the intertie may be inevitable, which would mean that control of the flow would need to be capable of dealing with the two flow paths.

A pipe from the Lander trunk to the treatment plant would add conveyance cost, but eliminate the potential need to rebuild the Lander regulator. Building a conveyance pipe would also remove the additional control complexity associated with conveying flow via the EBI and the intertie.

Use of the existing intertie pipe could reduce the sizing of a new intertie pipe somewhat if all flow were to be conveyed via interties. The existing intertie pipe is sloped to a high point between the Lander and Hanford trunks. If space for another pipe between the trunks is limited, another option might be to replace a good portion of the existing intertie pipe to reduce the pipe rise between the trunks and thereby increase capacity. Further modeling would be required to determine whether that would be sufficient to meet the flow needs.

Note that if a portion of the Lander captured overflow is conveyed to Hanford via the EBI and a portion is conveyed via the intertie pipe, correct sizing and control would be required to ensure the level in the Lander trunk remains above the level in the Hanford Trunk. Otherwise, the intertie flow might reverse, sending more flow from Hanford to Lander and then the EBI, then back to Hanford in the EBI. The flow that circled around in such a fashion would be drawn from the EBI at a somewhat lower elevation than it would be drawn from the Hanford Trunk, increasing possible pumping costs.

Michigan Brandon (MB)

A simplified steady state MOUSE model was developed to look at an approximate one year hydraulic grade line along the EBI with inflows from East Marginal and Brandon to be conveyed via the EBI to the treatment plant diversion point near the Michigan Regulator. The flow withdrawn from the EBI at the Michigan diversion point included flow from East Marginal pump station and some of the flow from the Brandon trunk, flowing back along the EBI. The model included the EBI from East Marginal pump station down to Brandon regulator.

The flow withdrawn from the EBI to treatment at Michigan was equal to the one year overflow from Brandon. Captured overflow from the Michigan trunk was assumed to be routed directly to the plant in order to limit the difficulty of achieving a workable hydraulic grade line. The Michigan trunk one year overflow is roughly equivalent to the EBI Mannings capacity, so a direct connection to the plant allowed for conveying other flows in the EBI without undue losses.

The one year overflow rates for the CSO location served by this plant follow.

Brandon	39 MGD
Michigan	40 MGD

The one year flow from East Marginal pump station is 41 MGD. This flow can be drawn from the EBI at Michigan to substitute for downstream overflow at Brandon that are captured and routed into the EBI.

Since the pumped one year flow at East Marginal exceeds the Brandon one year overflow, the initial assumption might be that diverting flow from the EBI at Michigan to treatment would be sufficient. However, in memo 2 of this series it was determined that since those peaks are not synchronized in time, an additional 14 MGD would need to flow back in the EBI from Brandon to the plant located at Michigan.

In order to draw the Brandon one year flow of 39 MGD from the EBI at Michigan, it is assumed, given the back flow of 14 MGD, that the flow from East Marginal is only 25 MGD at this point. Note that a more comprehensive long term model may find a wider variety of flow inputs that pose a variety of challenges. But, this will provide a first look at a possible one year hydraulic grade line.

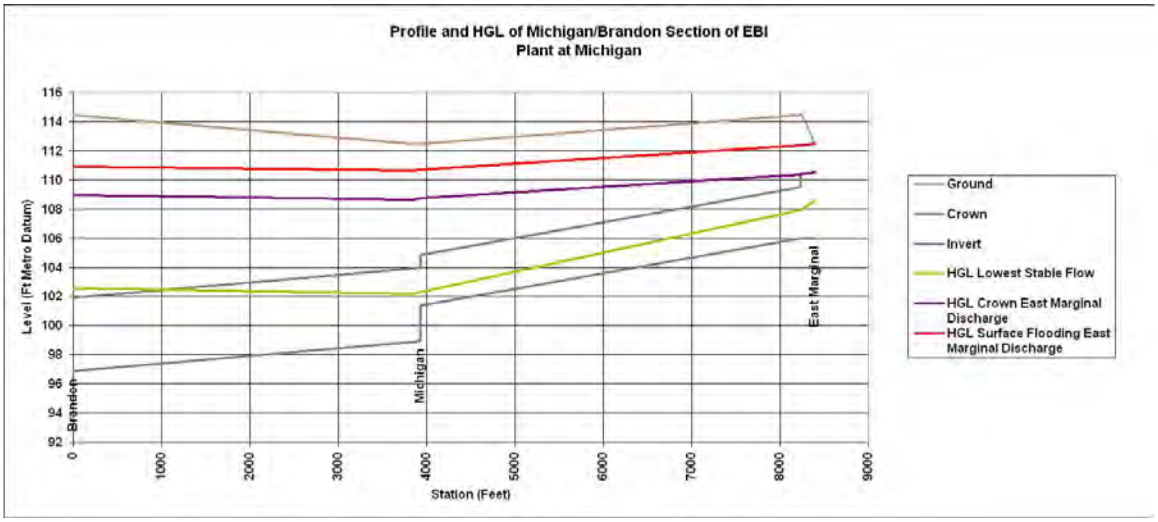
The existing one year conditions at Brandon were determined to be an interceptor level of 102.32 and an interceptor flow, downstream of the regulator, of 47 MGD.

It was not possible to match this downstream level and obtain the desired back flow to the treatment plant. The lowest EBI level with sufficient backflow was at 102.54 Feet Metro Datum as is noted below.

The additional flow, likely from an unregulated basin in the vicinity of Michigan, also could not be added while maintaining the backflow of 14 MGD. So these conditions were not utilized in this model.

As was indicated in the section on downstream conditions, the maximum and minimum workable downstream water levels were found by running the model and are shown on the profile which follows.

The profile from this run follows.



Graph 2 – East Marginal to Brandon Profile and Hydraulic Grade Line

This profile shows the hydraulic grade line (HGL), or water surface, from Brandon back to Michigan is only slightly sloped since the flow is limited. The HGL from East Marginal to Michigan almost matches the pipe slope in the lowest stable flow scenario.

The highest water surface remains at the East Marginal pump station discharge structure. The flow at East Marginal has been reduced in these model scenarios to maximize backflow, so the level at East Marginal is not an issue in either the lowest stable flow scenario or in the scenario matching the crown of the pipe exiting the discharge structure. More comprehensive modeling may find other situations where it is an issue.

Note that the water surface at Brandon must be 102.54, above the one year water surface of 102.32, in order to obtain sufficient back flow to compensate for the Brandon captured overflow inflow to the EBI. So, a gate in the EBI at Brandon may well be required to reverse sufficient flow from Brandon to Michigan to compensate for the Brandon captured overflow even when the transition to back flow has been accomplished.

The transition from a normal HGL, with flow all routed to Brandon and downstream, to the HGL shown above could also require control to ensure captured overflows are actually routed back to the plant and do not adversely impact Duwamish pump station and its CSO locations.

A gate in the EBI just downstream of Brandon would likely help ensure protection of facilities downstream of this section from excessive flows that may develop as the HGL transitions as the plant is started and maintain flow towards the plant as it operates. The profile above shows that the below grade vertical space above the EBI would be sufficient to allow for construction of such a gate.

Single CSO Treatment Plant

A single CSO treatment plant would require additional conveyance pipe between those Hanford and Michigan locations. The shortest straight line distance between those trunks is approximately 11,200 feet and the summed one year flows would be 221 MGD from the HLKK side and 73 MGD from the MB side. The cost of this additional conveyance could be compared to the savings and operational benefits that might be obtained from consolidation into one treatment plant.

Solids Deposition

The relatively low velocity of the backflow in the EBI may result in solids settling in those sections of the EBI. Since, in the best case, the transition out of treatment at the end of a storm is likely to be gradual, re-suspension of solids may not happen immediately. Further analysis of EBI velocity recurrences should be performed and likely velocities needed for re-suspension should be determined as part of more comprehensive modeling if this set of options is pursued.

Structures Required for the Control of Flows

A number of changes to the existing system will be required if flows are to be routed as indicated in this memo.

1) Capacity of the regulator gate and pipe from the trunk to the interceptor will need to be increased at a few of the locations where current overflow is to be directed into the interceptor.
2) The downstream boundary of the backwatered area may require a gate in the EBI to achieve and sustain the reverse in flow and an acceptable hydraulic grade line. In addition captured CSO from the trunk at the EBI gate location will need to be split between the down and upstream sides of the EBI gate, requiring two regulator gates.

3) The EBI flow diversion points will require gate(s) to divert flow to treatment, and might also require an additional gate in the EBI to sustain the reverse flow and an acceptable hydraulic grade line.
4) Depending on the tide level and the head loss through the selected treatment process, a pump station may well be needed to lift the diverted flow in the EBI up to the CSO treatment plant influent structure. Once the treatment process head loss can be estimated, the need for pumping in a variety of scenarios can be analyzed.

Regulator Pipe Capacity to EBI

Routing the captured overflow from the trunk to the EBI requires that the regulator gate and pipe capacity meet or exceed the desired flow rate. The table below compares the capacity, one year overflow rate and desired flow rate.

Location	Capacity Regulator to Interceptor (MGD)	One Year Overflow (MGD)	Trunk Inflow (Reg + Overflow) (MGD)
King	34	29	34
Kingdome	50	85	88
Lander	44	50	91 (problem)
Brandon	22	39	47

The gate and pipe capacities are calculated assuming that the existing regulator gates are full open and the level in the EBI and in the trunks are at modeled set points. Note that EBI levels may differ from the set points, per the HGL's shown above, but this will provide an initial look at capacity versus design flow.

The one year overflows are obtained from analysis in the prior memos.

The required flow capacity for this method of conveying flow to the plant was calculated by adding the regulator gate flow and overflow at each trunk and finding the summed one year flow. This is more conservative than using the one year overflow, but significant divergence from the one year overflow may indicate a problem with the modeling at that location.

Note that the flow for Lander of 91 MGD is significantly above the one year overflow rate of 50 MGD. This would need to be investigated further and probably reflects a modeling problem. The other flows are less than 10 MGD above their respective one year overflows, and are likely to be more accurate.

Comparing the approximate regulator gate and connecting pipe capacities to the desired flow rates, it appears that status is as follows:

King	capacity matches desired rate
Kingdome	capacity is insufficient and captured overflow might need to be split
Lander	need to investigate desired flow, capacity may be insufficient, captured overflow might need to be split
Brandon	capacity is insufficient and captured overflow needs to be split

At least two, and perhaps three, regulator structures would need to be rebuilt to allow additional captured overflow to be conveyed to the EBI.

Downstream Boundary Control Gates

Reversing flow direction in the EBI would be challenging. The analysis of flow in this memo is a simple first step in the analysis indicating peak flows could potentially be routed. A more complete analysis of how backflow will be achieved in the EBI without inducing surges that could adversely impact CSO locations further downstream (Elliott West for the HLKK plant and Duwamish pump station for the MB plant) will be required.

It appears more likely that a gate would be required downstream of Brandon to ensure proper backflow to Michigan, even without consideration of possible HGL transition challenges.

Until a more complete analysis is performed, it would be good to assume a gate would be required downstream of each back flowing section of the EBI to enforce a proper hydraulic grade line and properly direct flow. In addition, two regulator gates would be required to split captured overflow from the local trunk between the up and downstream sides of the EBI gate. This means that gates would be placed in the EBI downstream of Kingdome and Brandon trunks to work with the associated regulator gates to modulate flow and control the water surface level at the downstream end of the back flowing EBI sections.

Diversion Gates from EBI and Trunks and EBI Isolation Gates

The peak diverted flow from the EBI to treatment is 164 MGD at the Hanford location with an additional peak flow of 92 MGD from the Hanford trunk to treatment. The peak diverted flow from the EBI to treatment is 39 MGD at the Michigan location with an additional peak flow of 40 MGD from the Michigan trunk to treatment. A gate from the EBI to treatment and a gate from the trunk to treatment would be the minimum required at each location in order to divert this flow to treatment.

It is less likely that a gate would be needed in the EBI at the diversion point to separate the forward and back flowing sections to control flows and levels in the EBI. However, as was noted above, a more comprehensive analysis of transition into and out of treatment would be required to verify a simple set of diversion gates to the treatment plant would be sufficient.

System Failures

Another issue that must be addressed with more comprehensive modeling is what would be done when communication is lost with one particular location. Understanding what would be done in these cases depends on an understanding of how controls would route flows to treatment. There are two possible control methods that spring to mind.

One possible flow routing method would be for each regulator location to determine the amount of flow that would otherwise be sent to the outfall, but which is now routed into the EBI (up to the one year flow). The treatment plant would get these flow values and withdraw a flow equivalent to the sum of the inflows. The actual algorithm would likely be more complex due to travel times along the EBI and the need to manage the EBI HGL to achieve the desired flow direction. But the basic information that would drive the control algorithm would be flow values conveyed between facilities by the offsite control system.

If one regulator were to lose the ability to communicate its flow value, it would cease to overflow into the EBI and revert to the existing control settings, with excess flow going to the outfall. The treatment plant would see the loss of communications with the regulator as loss of its overflow, and adjust its treatment rate downward, after accounting for any prior flow already in transit.

However, since the treatment plant would be modifying the EBI water surface at the regulators, any regulator that lost communication might not be able to act like it normally does, because the EBI water surface it controls to would not be normal. In such a case, the isolated regulator on the trunk might continue to add flow to the EBI whether the treatment plant was aware of that inflow or not.

If the treatment plant or the downstream gate were to lose the ability to communicate, all contributing regulators would need to cease routing excess flow to the EBI and revert to the existing control settings, with excess flow going to the outfall. Any gates in the EBI would need to be opened to allow normal flow conditions to be re-established.

Overall this first method has the advantage of specifying the desired flows that should be treated. Its disadvantage is loss of communication at a regulator would result in a loss of the ability to control that regulator in a normal manner if the remainder of the treatment system were to continue to operate and manipulate the HGL in the EBI.

The second possible strategy for treatment plant control would be to set the downstream gate in the EBI to try to hold a downstream water surface until the upstream water level became too high. The plant influent gate from the EBI would attempt to hold either a desired flow rate or a maximum EBI water surface. Regulators would either function with a single interceptor level set point as they do now, or with dual set points, depending on whether the plant was operating or not.

The basic information that would drive the control algorithm in this case would be local levels and perhaps knowledge of whether the treatment plant was operating or not.

If either the plant or downstream gate were to lose communications, we would again be in a situation where the regulators would need to function as they do now.

This control method would reduce the amount of communication required between facilities, so that if a facility were to lose communications, the effect might be minimized. However, comprehensive modeling would be required to translate desired flow characteristics into level set points. An additional unknown is whether this method would actually work efficiently throughout the range of events that would be encountered over a long period of operation. Comprehensive modeling would be required to reduce that uncertainty.

In any case, comprehensive modeling would need to be performed to ensure we have a control algorithm that is both robust and efficient throughout normal storm events and in failure scenarios.

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Appendix B.5

Controlling Hanford #1 (Hanford@Rainier) and Bayview North CSOs

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CSO Project

Hanford at Rainier Pump Station Combined Sewer Overflow
Including the Bayview North and South Combined Sewer Overflows

The GSI team worked with the modeling group to identify the feasibility of eliminating the storage requirements at Bayview North and South which were identified in June 2010 as being uncontrolled. There is currently no identified project for Bayview North and South because the CSOs have shown to be controlled. The team looked closely at the operation of the Bayview system for modeling the system.

GSI was found to be feasible in the north end of the Hanford CSO basins that drained to Bayview. EPA SWMM is being used to identify sub-basin flow pre- and post-GSI.

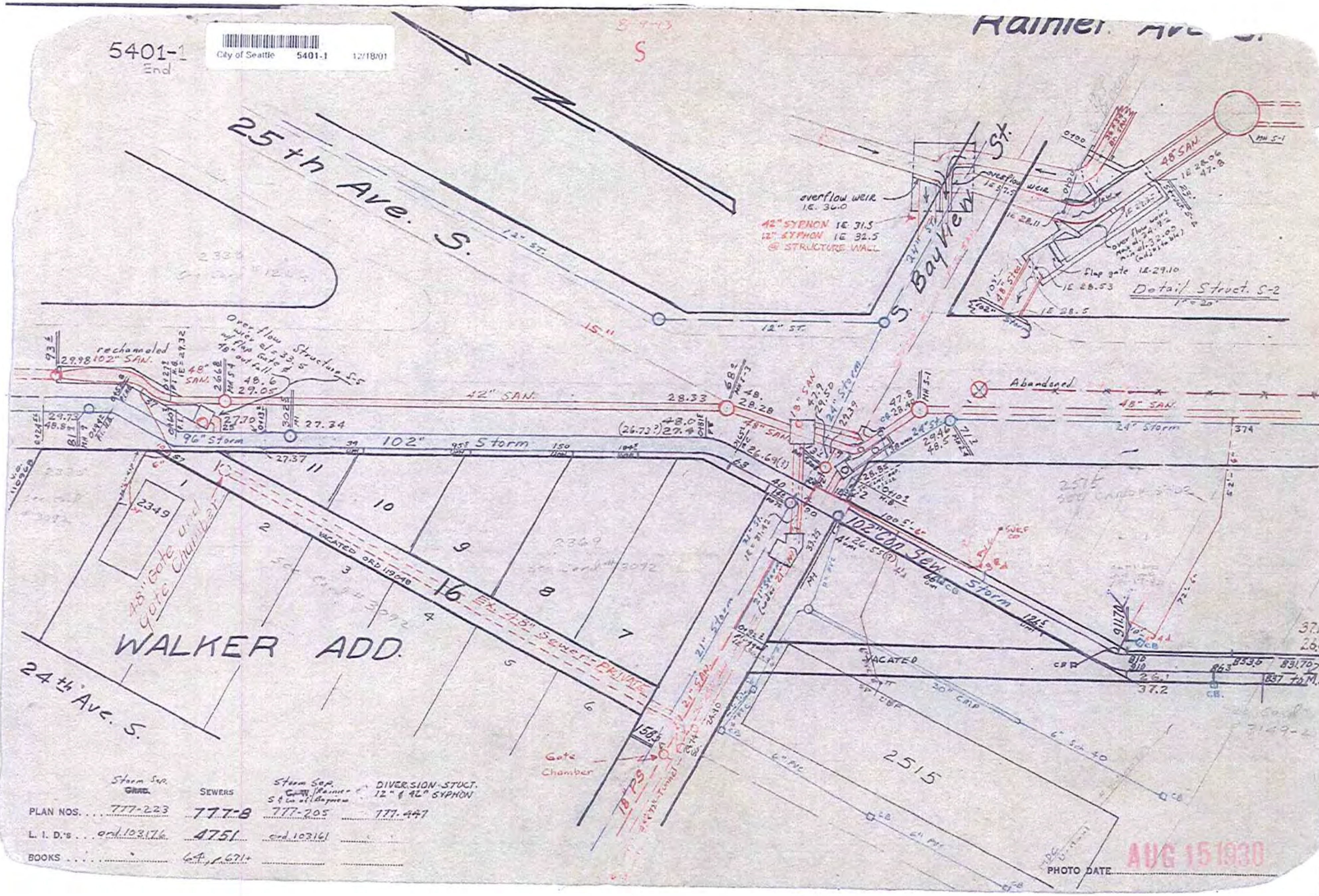
Planning Work to Date

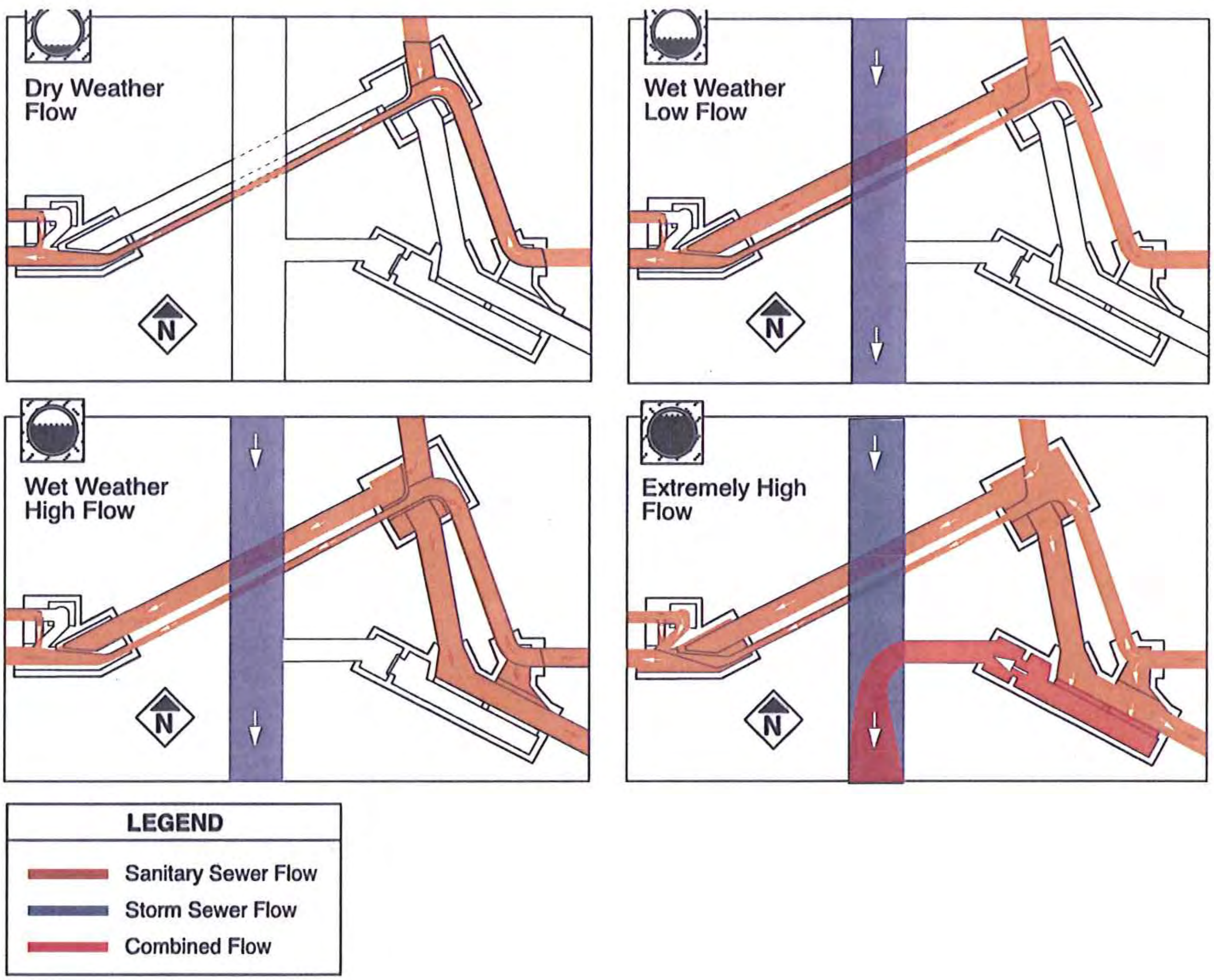
- Identified basin and sub-basin boundaries, confirmed through pipe routing
- Identified connected impervious surfaces (GIS analysis)
- Calibrated MOUSE Model to sixteen portable flow meters each covering 1-2 years of data (within 2007-2010 range). Storage volume needed is 1.13 MG Hanford @ Rainier and 0.77 MG at Bayview North.
- Identified feasible areas for Green Stormwater Infrastructure
- Confirmed weir elevations and overflow points for Bayview North and South
- Inspected pipe structures at Bayview North and South (photos)
- Flow meters at the base of sub-basin 225 installed October 2010 and upstream of Bayview North
- Calibrating EPA SWMM model for sub-basin 225 (prime basin for GSI)
- Partnership with Yesler Terrace redevelopment and Seattle University for stormwater management
- Ran MOUSE model with conveyance upgrades at Bayview North to eliminate storage at Bayview
- Pump tests at Rainier were done Sept 26, 2007. Problem definition will not be complete unless we choose to accelerate inspections – in 9/07 Mika stated: The raw sewage pumps were upgraded in 2000, and in the past 3-4 years we installed a new standby generator, new drives, controls, and according to O&M "pretty much everything is new". So the station is in good shape and we're not scheduled to consider pump replacement until 2030".
- Confirm eliminating storage at Bayview in MOUSE Model. Looked at a couple options in the Bayview area over 32 year modeling run. Changing the 42" pipe from Bayview North to Bayview South does not help much, Reconnecting the abandoned 48" pipe under Bartells. Findings are:
    - Bayview North would be controlled – 21 overflows in a 32 year period
    - Bayview South has more overflows but is still controlled – 17 overflows in a 32 year period (was 7 overflows)

  - Hanford @ Rainier 1-yr peak flows and volumes DECREASE. 1-yr volume goes from 1 million gallons to 343,000 gallons. Flow from 17.2 to 9.6 mgd.
- Changed the model around and to the Bayview Tunnel. The flows and volumes changed just a little from the previous 32-yr model run. The volume at Bayview North stayed the same. The volume at Hanford @ Rainier increased from 0.99 million gallons to 1.02 million gallons. Added the 48" pipe from Bayview North to the entrance to the Bayview Tunnel. The connection at Bayview North has no consideration to how it would pass under the stormwater pipe; it is just a simple connection. Under current conditions, the model shows that the Bayview Tunnel does not fill to capacity during storm periods. The flow is constricted in Bayview South in the dual siphons. They do not allow enough flow through to fill the tunnel to capacity. They also cause the flow to backwater up to Bayview North and overflow. Adding the 48" pipe does a couple of things. It allows some of the flow to bypass Bayview South thereby filling the tunnel to capacity if needed. It also keeps the water levels lower at Bayview South so there are fewer overflows to Hanford @ Rainier.
- Private sewer line is owned by Worthington Real Estate, LLC.

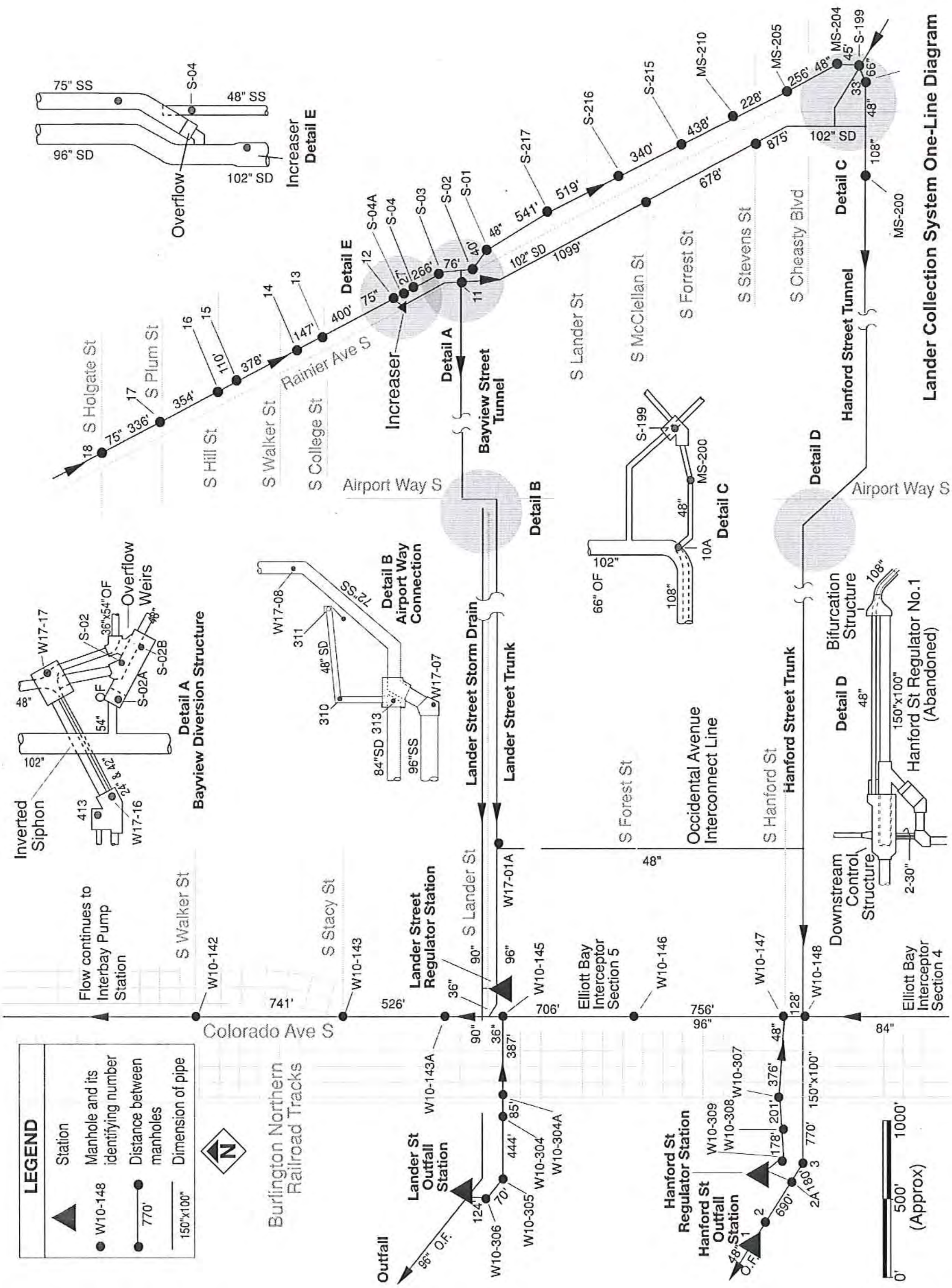
Future Work

- Inspect Hanford at Rainier Overflow Structure
- Add GSI model output to MOUSE model for Grey/Green alternative
- Inspect abandon 48" line under Bartell Drugs to use for conveyance improvement to eliminate storage at the Bayview CSOs
- Revise storage estimate for the Hanford at Rainier storage tank based on conveyance and GSI
- Update MOUSE Model with available 2010-2011 flow data
- Analysis made at Lander and Hanford regulators with increased flow from Bayview North. The 1-yr peaks and volumes should increase.
- The flow meter on the dry side has shown that the flapgate may be a little leaky. There are elevated water levels before the wet side is over the weir height. This needs to be verified.
- Engineering & Construction feasibility of re-connecting 48" private sewer line to the Bayview North overflow
- Survey elevations to confirm.
- 3D model?


5401-1
End
City of Seattle 5401-1 12/18/01
Rainier Ave. S.
25th Ave. S.
S. Bayview St.
24th Ave. S.
WALKER ADD.
42" SAN.
102" Storm
96" Storm
48" SAN.
24" Storm
Abandoned
102" Con. Sew.
Storm
overflow weir IE. 36.0
42" SYPHON IE 31.5
12" SYPHON IE 32.5
@ STRUCTURE WALL
Detail Struct. S-2
Flap gate IE 29.10
Overflow Structure S-5
rechanneled 102" SAN.
48" Gate and Gate Chamber
Gate Chamber
Ex. 48" Sewer-PRIVATE
VACATED ORD 119048
VACATED
30" CMP
2515
2349
Storm Sep.
SEWERS
DIVERSION STRUCT. 12" & 42" SYPHON
PLAN NOS. 777-223 777-8 777-205 777-447
L. I. D.'s ord 103176 4751 ord 103161
BOOKS
PHOTO DATE AUG 15 1930



Types of Flows from Bayview Diversion Structure


Lander Collection System One-Line Diagram
LEGEND
Station
Manhole and its identifying number
Distance between manholes
Dimension of pipe
W10-148
770'
150"x100"
Detail A
Bayview Diversion Structure
Inverted Siphon
Overflow Weirs
Detail B
Airport Way Connection
Detail C
Detail D
Hanford St Regulator No.1 (Abandoned)
Bifurcation Structure
Downstream Control Structure
Detail E
Increaser
Overflow
75" SS
48" SS
96" SD
102" SD
Bayview Street Tunnel
Hanford Street Tunnel
Lander Street Storm Drain
Lander Street Trunk
Hanford Street Trunk
Occidental Avenue Interconnect Line
Lander Street Regulator Station
Lander St Outfall Station
Hanford St Regulator Station
Hanford St Outfall Station
Outfall
Flow continues to Interbay Pump Station
Elliott Bay Interceptor Section 5
Elliott Bay Interceptor Section 4
Colorado Ave S
Burlington Northern Railroad Tracks
Airport Way S
Rainier Ave S
S Holgate St
S Plum St
S Hill St
S Walker St
S College St
S Lander St
S McClellan St
S Forrest St
S Stevens St
S Cheasty Blvd
S Stacy St
S Forest St
S Hanford St
0' 500' 1000' (Approx)

Appendix B.6

Diverting Chelan Ave CSOs to Alki Treatment Facility

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Memorandum version 1

Date: **November 18, 2010**

From: **Bruce Crawford**

To: **Karen Huber**

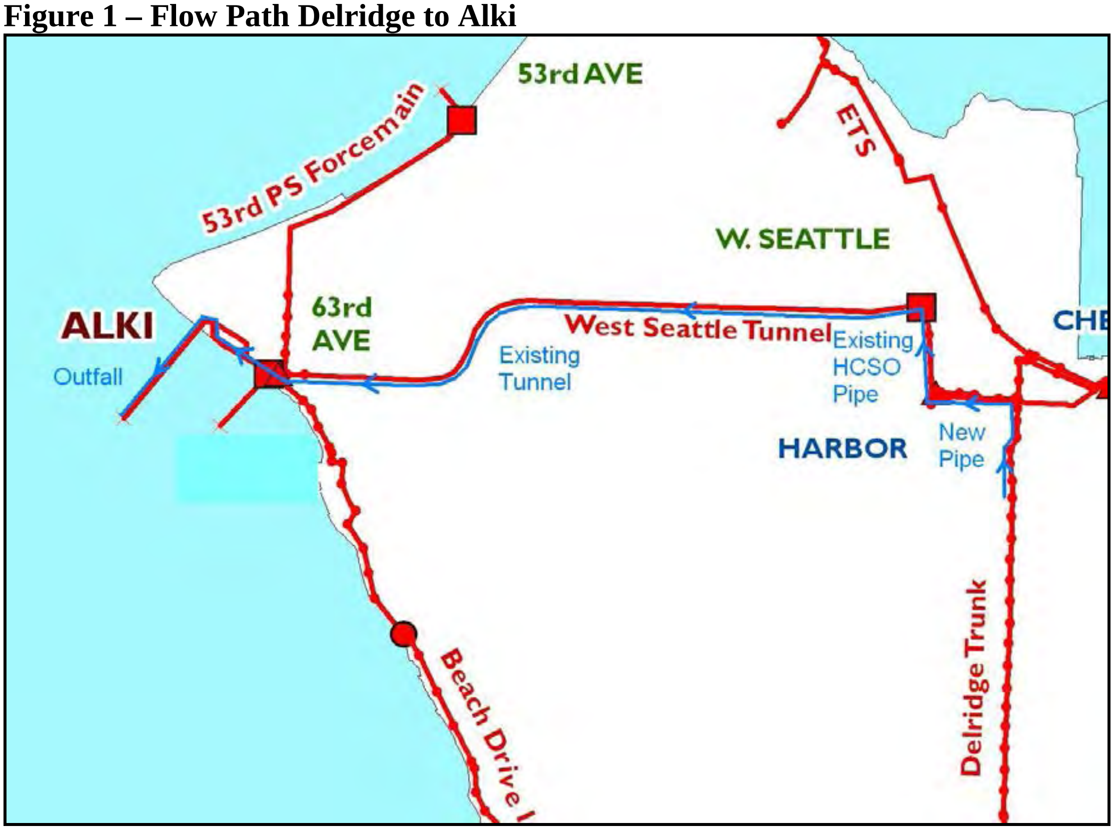
Subject: **Chelan CSO Diversion to Alki CSO Plant**

One suggested alternative for controlling the Chelan CSO is to route flow to the Alki Treatment Plant. While many variations on routing and structures would be considered during an actual design process, for the purposes of this initial evaluation, one alternative that appears to be workable and minimizes obvious construction costs has been provided.

Flow Route

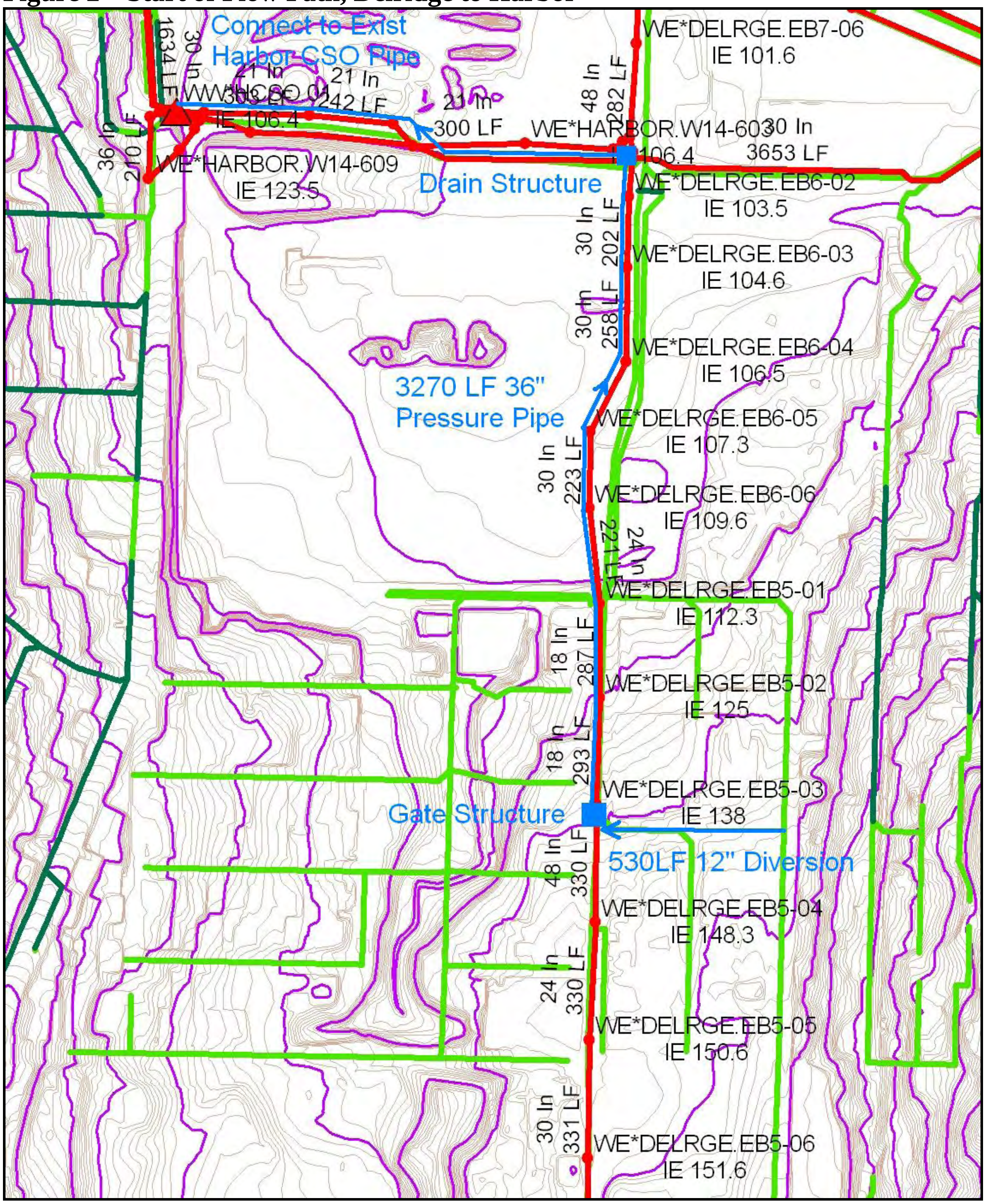
The route, shown below in Figure 1, is to parallel a portion of the existing Delridge Trunk with a new pressure pipe, then turn west to the Harbor Regulator to join the existing HCSO pipe from Harbor Regulator to West Seattle Tunnel near the West Seattle Pump Station. The flow would continue from the Splitter Structure adjacent to the West Seattle Pump Station west in the existing West Seattle Tunnel to 63rd Pump Station.

Figure 1 – Flow Path Delridge to Alki



Much of the work required is in the new pipe and structures at the beginning of the diversion path, shown below in Figure 2. The remainder of the work is at the end of the flow route, adjacent to 63rd Pump Station and Alki CSO Treatment Plant.

Figure 2 – Start of Flow Path, Delridge to Harbor



Flow Quantities to Be Diverted

The one year overflow rates at Chelan and Harbor regulator stations, as determined from the September 2010 runs are as follows.

Chelan Overflow	25.7 MGD
Harbor Uncontrolled Overflow	14.4 MGD
Harbor Captured Overflow	23.2 MGD
Harbor Total Overflow	24.1 MGD
Chelan/Harbor Total Overflow	45.7 MGD

Note that the "Harbor Total Overflow" includes flow currently captured and routed to the HCSO pipe and overflow that still is uncontrolled. Those two timeseries were added together to obtain the "Harbor Total Overflow". The "Chelan/Harbor Total Overflow" is calculated by adding the "Chelan Overflow" and "Harbor Total Overflow" timeseries. It is slightly less than the sum of the individual one year overflows because peaks in those timeseries do not occur at exactly the same time.

Major New Facilities, Pipes and Upgrades

The major new elements that would need to be constructed for this diversion are as follows:

Delridge Diversion Pipe – This is a 530 LF, 12 inch diameter local diversion pipe that serves to ensure the largest possible basin is diverted from the Delridge area to control the Chelan CSO. This pipe is shown on Figure 2, above.

Delridge Gate Structure – This structure would divert flow from the existing Delridge 18 inch Trunk into a new 36 inch pressure pipe. The gates would be 36 inches and 18 inches in size, to match the downstream pipe diameters. This structure is shown on Figure 2, above, and would be located in the vicinity of WE*DELRGE.EB5-03.

Delridge to Harbor Pressure Pipe – This 36 inch pipe would be approximately 3300 feet long and convey flow from the Delridge Gate Structure to the Harbor Regulator, where it would connect to the existing Harbor CSO Pipe (HCSO). This pipe is shown on Figure 2, above.

Delridge Drain Structure - This structure would drain remaining water from the Delridge to Harbor Pressure Pipe back to the lower Delridge Trunk after a storm event has passed. It could also be used during a storm event to allow a small fraction of flow to continue to the lower trunk to prevent sediment build up as a storm progressed. The drain valve size might be around 12 inches. This would be small enough to allow flow control under elevated pressures and large enough to allow sediment to pass. A redundant drain path might be provided for maintenance in case of plugging of the valve. This structure is shown on Figure 2, above, and would be located in the vicinity of WE*DELRGE.EB5-01.

Alki Regulator Gate – This existing gate is between the 63rd Pump Station and the West Seattle Tunnel. This gate may need to be upsized to allow sufficient flow through without excessive loss.

63rd Pump Station and Alki CSO Treatment Plant – These facilities would need to be upsized to handle the additional flow associated with the CSOs to be controlled. The outfall is one element of particular concern, as are the fixed speed pumps at the 63rd pump station. However, it is likely all elements would need to be reviewed in order to determine all the upgrades required for proper performance. This is a significant task in itself and for now remains one of the larger sources of uncertainty.

Flow Loss Calculations

A quick spreadsheet calculation of losses in pipes at the design flows was performed in order to determine whether there were any immediately apparent fatal flaws and also to determine how far up the Delridge Trunk the Delridge Gate Structure would need to be to adequately pressurize the pipe to convey the diverted CSO flow.

The flows noted above were used, along with the pipe layout, in order to generate a hydraulic grade line from 63rd Pump Station to a point along the Delridge Trunk where flow could be diverted. Pipes were assumed to be flowing full for this analysis.

The downstream level at 63rd Pump Station would be between 101.5 Feet Metro Datum, as low as the entry into the pump station can be adjusted, and 106.0, at which point there would be overflow at the structures adjacent to the pump station. Working upstream from that location, the upstream water surface at the diversion on the Delridge Trunk would be between 129.1 and 133.6 Feet Metro Datum. The diversion point on the Delridge Trunk was selected so as to ensure this upstream water surface could be obtained without surcharging.

A more detailed analysis may result in some adjustment of the diversion point and optimization of the design. However, this analysis has been performed simply to allow for a planning level estimate.

The spreadsheet file is chelan2alki_hgl.xls, which should be transmitted with this memorandum.

Simplified Hydraulic Grade Line Chelan & Harbor CSO's to Alki

One Year CSO Flows	Flow (MGD)
Chelan	25.7
Chelan plus Harbor	45.7

HGL from downstream (63rd PS) to upstream (Delridge)
Simplified, assumes pipe full along entire route.
Elevations are Feet Metro Datum

Highest Downstream Level	106
Lowest Downstream Level	101.5

ID	Flow (MGD)	Flow (CFS)	Diameter (Ft)	Area (SF)	Velocity (FPS)	Velocity Head (Ft)	f value	Length (LF)	K	US IE	DS IE	Friction Loss	Minor Loss	Total Loss	DS HGL	US HGL	Comments
63rd to WSEA Tunnel	45.7	70.6979	6	28.27	2.50	0.10	0.040	500	0.5	100	99.02	0.32	0.05	0.37	106.00	106.37	Remove or upsize gate
WSEA Tunnel	45.7	70.6979	9.5	70.88	1.00	0.02	0.040	10223		99.02	84.7	0.66	0.00	0.66	106.37	107.04	
WSEA Tunnel to Splitter	45.7	70.6979	9	63.62	1.11	0.02	0.040	55		84.7	84.59	0.00	0.00	0.00	107.04	107.04	low point at Splitter
Drop	45.7	70.6979	4.5	15.90	4.45	0.31	0.040	1	2	100.9	84.59	0.00	0.61	0.62	107.04	107.66	drop plus 120 deg bend plus vel decrease
HCSO to WSEA PS Drop at Spitter Structure	45.7	70.6979	4.5	15.90	4.45	0.31	0.040	39	0.4	101	100.9	0.11	0.12	0.23	107.66	107.89	2 at 45 deg bends
HCSO	45.7	70.6979	4.5	15.90	4.45	0.31	0.040	1412	0.2	105.93	104	3.85	0.06	3.91	107.89	111.80	45 deg bend
HCSO	45.7	70.6979	4.5	15.90	4.45	0.31	0.040	50	0.2	106	105.93	0.14	0.06	0.20	111.80	112.00	45 deg bend
HCSO from Harbor Regulator	45.7	70.6979	4.5	15.90	4.45	0.31	0.040	41		107	106	0.11	0.00	0.11	112.00	112.11	
New Pipe from WE*DELRGE.EB-03 to Harbor	25.7	39.7579	3	7.07	5.62	0.49	0.040	3200	1			20.96	0.49	21.45	112.11	133.56	

Highest Upstream Level	133.56
Lowest Upstream Level	129.06

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