Appendix I

Evaluations for Dexter Ave CSO Site

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Appendix I.1

Dexter Control Modifications

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MEMORANDUM v1.2

Date: **May 3, 2011**

From: **Bruce Crawford**

To: **CSO 2012 Update**

Subject: **Control of Dexter CSO**

As part of the Denny/Lake Union CSO control project, an overflow to the new Mercer Tunnel from the Central Trunk upstream of the Dexter Regulator was constructed to achieve CSO control of Dexter. That project was completed in mid-2005. This reduced the amount of flow reaching the regulator during storms, and has greatly reduced the volume of overflow. However frequent small overflows have continued to be seen. This type of overflow indicates that the facility is very close to control. This memo describes the analysis of the causes of the remaining overflows and the control system adjustments that have been made to complete CSO control.

Dexter CSO regulator operates differently from most other regulators in our system. It consists of a regulator gate that modulates flow to the downstream portion of the Central Trunk, with a weir just downstream of the regulator gate. The regulator gate serves the functions of both a regulator gate and overflow gate, restraining flow to fill the upstream trunk and then allowing flow after the upstream trunk has reached its maximum acceptable level. This means the regulator gate has a more complex control function than most gates.

As is common in CSO control projects, the ability to test the effectiveness of corrections is limited to wet seasons and storms of a sufficient size. At Dexter the effort has been ongoing since the higher overflow frequency was verified, with control changes followed by evaluation of the effects in an iterative cycle. The complexity of the original control algorithm has meant that increasingly subtle, but important, modifications have been made.

There are three significant challenges to controlling the Dexter CSO:

1. The facility design makes control of CSO's to a once per year limit difficult. The regulator gate is large, so when the upstream level is high it is difficult to modulate the flow well without releasing large amounts of the stored upstream flow volume. Small adjustments in the gate result in large changes in flow. The bypass gate serves as a reasonable surrogate, preventing flooding in the regulator and in upstream basements, but it does not modulate and is also large. It will not provide fine levels of control.

2. The second challenge is the nature of the service area. It is highly impervious and most of the stormwater is routed into the combined sewer system, causing extremely rapid rises to high peak flows. Rapid gate operation is needed to respond to these flows, but overshooting the "ideal" position at any point in time is a risk. Complicated by the challenges of large gate size, algorithms may "hunt" for the best position causing flow oscillations that may lead to overflows.

3. The third challenge results from the Dexter control approach of maximizing transfer of flow into the Mercer Tunnel. This requires that the maximum allowable upstream level be set as high as possible. As a result there is little vertical difference between maximizing the use of upstream storage and possible flooding, as well as maximizing downstream conveyance and causing overflow at the downstream weir. These narrow vertical operational ranges for control of the gate may decrease modulation precision.

The goal of control system refinement at Dexter CSO is to maximize use of upstream storage and transfer and downstream conveyance while minimizing overflows. This requires that the regulator gate move quickly, but avoid overshooting its optimal position during rapid changes in flow. Increasingly subtle changes to the algorithms have been added to achieve this objective. Maximizing the utility of the existing facility depends on knowledgeable adjustments to the details of the algorithm.
The process and changes are documented below in chronological order.

Chronology of actions:

April 2007 – WTD verified Dexter overflows are more frequent than projected after completion of the connection to the Mercer Tunnel/Elliott West CSO Control Project.

May 2007 –Determined that control modifications should be made after the expected PLC replacement occurs.

August 2007 – New PLC with revised programming installed.

The original algorithm for Dexter outlined in the operations manual has the regulator gate modulating based on the downstream interceptor level to avoid overflows, and the bypass gate (open/shut only) operating when the upstream level gets too high. The use of an open/shut bypass gate can result in a surge of water being released, which then may cause an overflow.

An early modification to the algorithm had been to provide regulator gate control based on both the up and downstream levels. However, this was not sufficient to control the CSO.

A next control algorithm involved modulation of the gate based on the downstream interceptor level. Then if the upstream trunk level became too high, risking flooding, the gate would modulate more open. Similar to the previous algorithm, this would minimize overflow volumes by eliminating release of all the upstream stored volume by the bypass gate unless there was an exceptional rainfall event or equipment failure. CSO's would be reduced more by allowing the trunk level to rise as high as possible, but avoiding flooding.

October 2008 – The interceptor level filter time constant was adjusted to correct gate, flow and level oscillations.

December 2008 – Revised algorithms were installed. These included:

- The downstream control will modulate the gate from 40% to 0% over the range of 136.25 to 138.25.

- The upstream control will modulate the gate through a total active range of 0 to 40% open using a gate travel range of 10% width at any given time for a level range of 142.25 to 143.25. Once the gate position approaches either end of the level range an “automatic reset” feature is used to shift to the next 10% increment of gate travel range, with overall limits, as noted above of 0 to 40% open. In this way, a relatively narrow elevation range can provide “fine tuning” of the gate position, but also provide for larger movements when needed.

- A mode positioning the gate at 100% until called into service by upstream or downstream flood conditions has been added. This feature was added so that the hydraulic actuator spends 99.99% of its life fully retracted which should prolong the life of the system by reducing exposure to damp/corrosive conditions.

- The float switch actuating the bypass gate will trip at 9.0 feet above the center of the channel measured approximately two feet upstream of the gate.

October 2009 – controls were adjusted to allow the regulator gate to be at around 50 to 60% open when storm flows arrive.

November 2010 – Two problems modulating the gate closed were identified.

1. This rule controlling modulation of the gate closed was active when the downstream level exceeds a tripwire level. However, adjustment of the gate could send the downstream level below the level at which it is set to an inactive, full open, state. This could occur due to gate activity even in the middle of a storm, when opening the gate would result in an overflow. (Note that regulator gates are set full open when not in operation such that the hydraulic operator shaft retracts into the cylinder. This prevents corrosion of the shaft, damage to the seal and leakage of hydraulic fluid.)

    Solution 1: The level at which the gate becomes active - closing to 50% open and then modulating - was changed to when the downstream level exceeds 135.5 or the upstream trunk level exceeds 137.0. Since the upstream level will not drop if the gate modulates closed, the rule will not easily be deactivated by gate adjustments. 137.0 level is just above dry maximum water surface levels, so the gate will tend to remain active throughout storm events.

2. Gate adjustments with relatively large gate openings can cause oscillations, resulting in high downstream levels and overflows. Two solutions were evaluated:

    Solution 2a: Apply a secondary PID algorithm which will identify a gate position to hold a downstream level set point below the weir level. Recommended PID set point is 137.9 feet Metro Datum which slightly above the downstream crown to maximize interceptor flow and to account for hydraulic losses, but below the weir. Gate openings will be limited to the lesser of the opening suggested by the existing range algorithm and the new PID algorithm. This will reduce severity of gate oscillations on the opening side, thereby reducing the chance of overflow. The risk in using dual algorithms is that a jump in gate position could occur as settings change from being driven by one algorithm to another. This algorithm has not been implemented at this time, but is noted here as being considered.

Solution 2b: Limit the maximum opening of the regulator gate to 20% when controlled by the downstream level sensor. This should allow up to 60 MGD into the interceptor (its approximate maximum capacity) without raising the upstream level into the control range for modulating the gate open. The gate will not open more than 20% unless the upstream level sensor detected a water surface in its control range, starting at 142.25 Ft Metro Datum. At that point the upstream algorithm would start to modulate the regulator gate open to prevent upstream flooding. When that occurs, an overflow will become more probable.

Solution 1 was applied at the end of 2010. Some settings suggested in solution 2 have been applied on an experimental basis. No storms sufficient to test the effectiveness of these control adjustments have occurred since implemented. Monitoring will continue into the next wet season.

Appendix I.2

Green Stormwater Infrastructure Projects

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GSI PROGRAM MEMORANDUM

Project Name: 2012 CSO Program Review **Date:** September 19, 2011

Prepared By: John Phillips, Shaun O'Neil, Tiffany McClaskey

Subject: Dexter CSO Stormwater Review

Distribution: King County, Project Team

Despite the addition of an overflow to the new Mercer Tunnel, which has reduced the volume of CSOs in the Dexter basin, there are still frequent small overflows. This type of overflow indicates that the facility is very close to control. One of the challenges in reaching full control over the Dexter basin is the large amount of impervious surfaces directing rain water into the CSO which causes sharp peaks in the flow rate in the pipe. The consequential rapid movement of the large regulator gate in the pipe can cause overflows for reasons detailed in Control of Dexter CSO Memorandum (Crawford, 2011).

The reduction of impervious area runoff contributing to the flow at the regulator gate will reduce the size of the peak in flow rate during storms. Since the Dexter CSO is close to being under control, the reduction in contributing impervious area from the use of green stormwater infrastructure (GSI) at the Seattle Center in conjunction with the modifications of the gate's operation currently being explored could achieve control of the Dexter CSO without the addition of a storage tank.

King County is working closely with major projects in the Dexter CSO basin, including the North Access Viaduct (WSDOT), Mercer Corridor Project (SDOT) and Seattle Center Capital Improvements. This memorandum details work at Seattle Center. There is limited design information on the two transportation projects, since they are just starting the design process. As more information becomes available, the information will be updated. The stormwater volume reduction should help control the Dexter CSO to one event per year by 2016.

Transportation Projects

Both transportation projects will detain stormwater from new and replaced impervious surfaces to meet the City of Seattle Drainage Code. Once 30% design is reached on these projects SDOT and WSDOT will provide King County with total stormwater detention volumes. The projections below are from each project's Environmental Impact Statements (EIS). Both projects need to meet minimum requirements for peak-flow control as per Seattle Drainage Code (22.805.080.B.4) "The post-development peak flow with a 25-year recurrence flow shall not exceed 0.4 cubic feet per second per acre. Additionally, the peak flow with a 2-year recurrence flow shall not exceed 0.15 cubic feet per second per acre."

Table 1 – Estimated Transportation Project Stormwater Volumes

Project	Est. Area Mitigated (sf)	Est. Detention Volume (gal)	Year Complete
SDOT – Mercer Corridor	22,500	28,000	2016
WSDOT – AWV North Portal	845,000	1,053,000	2015

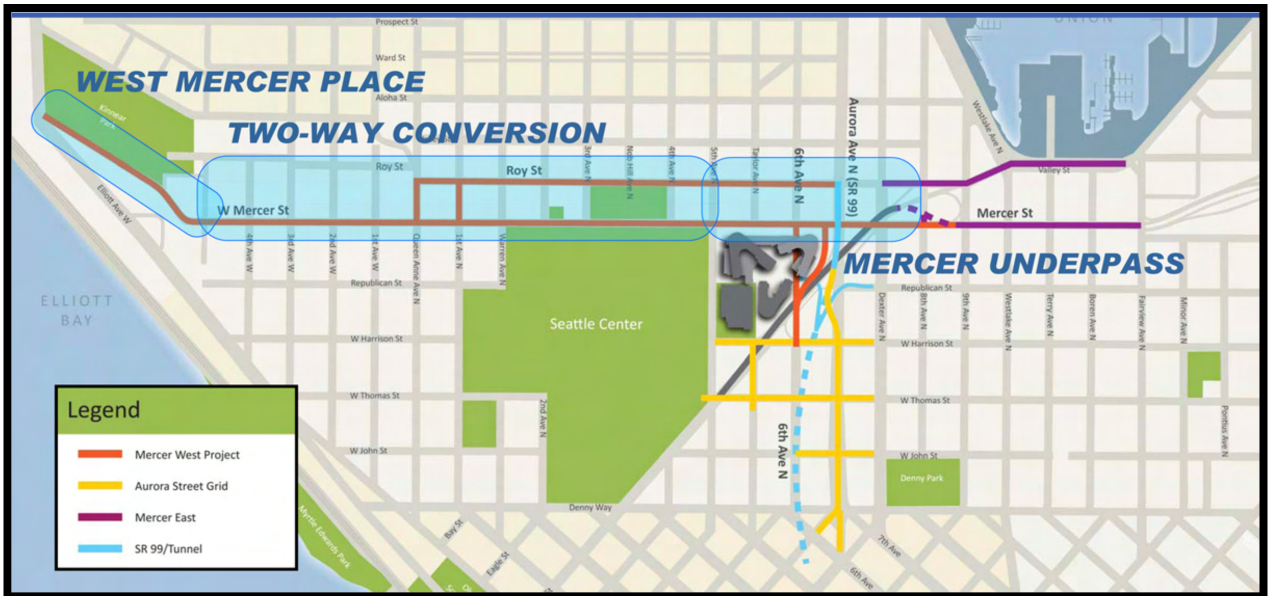


Figure 1 - Map of Alaska Way Viaduct (AWV) and Mercer Corridor Project. Courtesy of Seattle Department of Transportation.

Seattle Center Green Stormwater Infrastructure Partnership

Seattle Center is currently embarking on a long term capital improvement program to replace and upgrade facilities. Stakeholders are interested in implementing GSI on the Seattle Center campus to the maximum extent feasible. King County and Seattle Center are working on plans to mitigate impervious surfaces on campus. Seattle Center is 74 acres including the privately held Pacific Science Center and there is a total of 58 acres of impervious areas in hardscape and roof area.

Table 2 outlines several projects that are in development or suggested as early pilot projects for Seattle Center. Several large areas of Seattle Center are proposed for redevelopment including the new Chihuly Garden and Glass Project, Pacific Science Center and the Memorial Stadium Redevelopment. To provide some level of stormwater controls prior to the master plan redevelopment, several pilot projects are available that will demonstrate the effectiveness of GSI mitigating existing buildings.

Table 2 – Seattle Center Projects

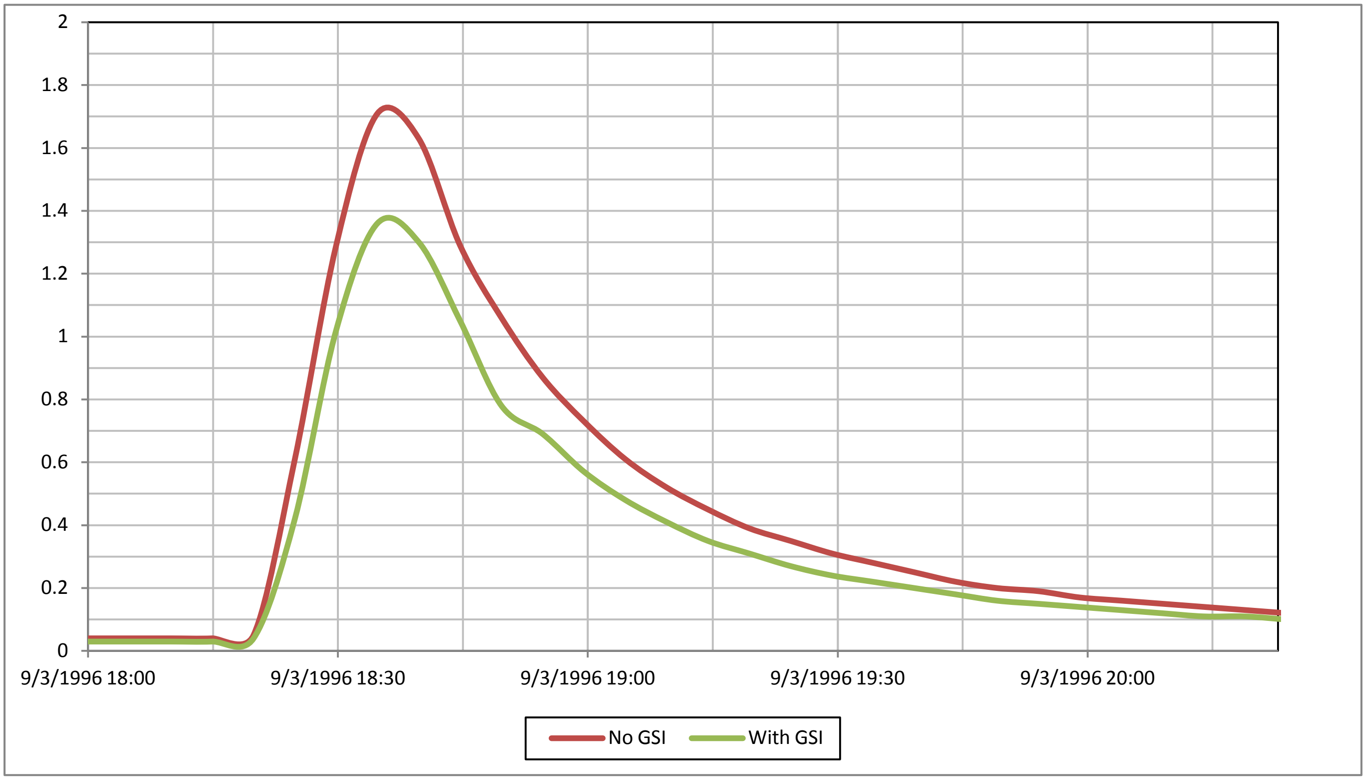
Project	Est. Area Mitigated (sf)	Year Completed
Key Arena ½ Roof Rainwater Harvesting	75,000	2014
Chihuly Museum	16,000	2012
Rain Gardens for Walkways	13,000	2015
Northwest Rooms Roof to Permeable Pavement	51,000	2016
Northwest Rooms Roof to Rain Garden	5,000	2016
Pacific Science Center incremental GSI projects	TBD	2016
Seattle Children's Theater Roof	10,000	2017
Monorail Station Green Roof	4,000	2020
Intiman Theater Awning	5,000	2022
International Fountain Plaza	19,000	2024
Incremental campus-wide Permeable Pavement	62,000	2024
Fisher Pavilion	20,000	2024
TOTAL	280,000	

The storms in Table 3 include the five largest storms in peak flow rate and the five storms with the largest total volume over the course of the storm. The other storms included on the list are one year CSO storms based on peak flow and based on volume. These storms were chosen from a list of 16 one year CSO storms. The ranking provided in the table is based on the output from EPA SWMM. The values for the projected flows out of the Seattle Center once the GSI projects are implemented is based on a SWMM model where the sizing factor for GSI from the Seattle Drainage Code was used to calculate the impervious area mitigated for each section of GSI suggested for the Seattle Center.

Table 3 - EPA SWMM output of storm peaks and volumes associated with 32 years of rain data in the area

Date and Peak Time of Storm	Peak Flow (MGD)	Peak Flow after GSI (MGD)	Peak Flow Reduction %	Storms Rank by Peak Flow over the 32yrs Modeled (MGD)	Total Volume (gal)	Volume after GSI (gal)	Volume Reduction %	Storms Rank by Volume over the 32yrs Modeled (MGD)
8/24/1978 18:55	1.32	1.03	22.0%	8	149,583	20,660	13.8%	14
11/3/1978 22:15	1.51	1.18	21.9%	4	299,479	51,458	17.2%	6
10/5/1981 22:50	1.30	1.02	21.5%	9	465,000	91,875	19.8%	2
1/18/1986 19:15	1.33	1.04	21.8%	7	461,597	92,326	20.0%	5
11/21/1988 14:55	0.91	0.67	26.4%	21	209,306	31,597	15.1%	36
9/4/1992 0:40	0.84	0.66	21.4%	27	174,236	26,354	15.1%	26
5/13/1996 0:04	1.74	1.36	21.8%	2	196,389	25,590	13.0%	16
9/3/1996 18:35	1.71	1.36	20.5%	3	110,313	17,535	15.9%	13
10/20/2003 8:45	0.92	0.72	21.7%	20	449,965	85,451	19.0%	4
8/22/2004 5:19	1.85	1.45	21.6%	1	303,611	52,708	17.4%	3
12/3/2007 10:30	1.10	0.85	22.7%	28	749,167	148,090	19.8%	1
9/29/2009 18:00	0.97	0.75	22.7%	19	111,007	15,104	13.6%	28
		Average	22.1%			Average	16.9%	

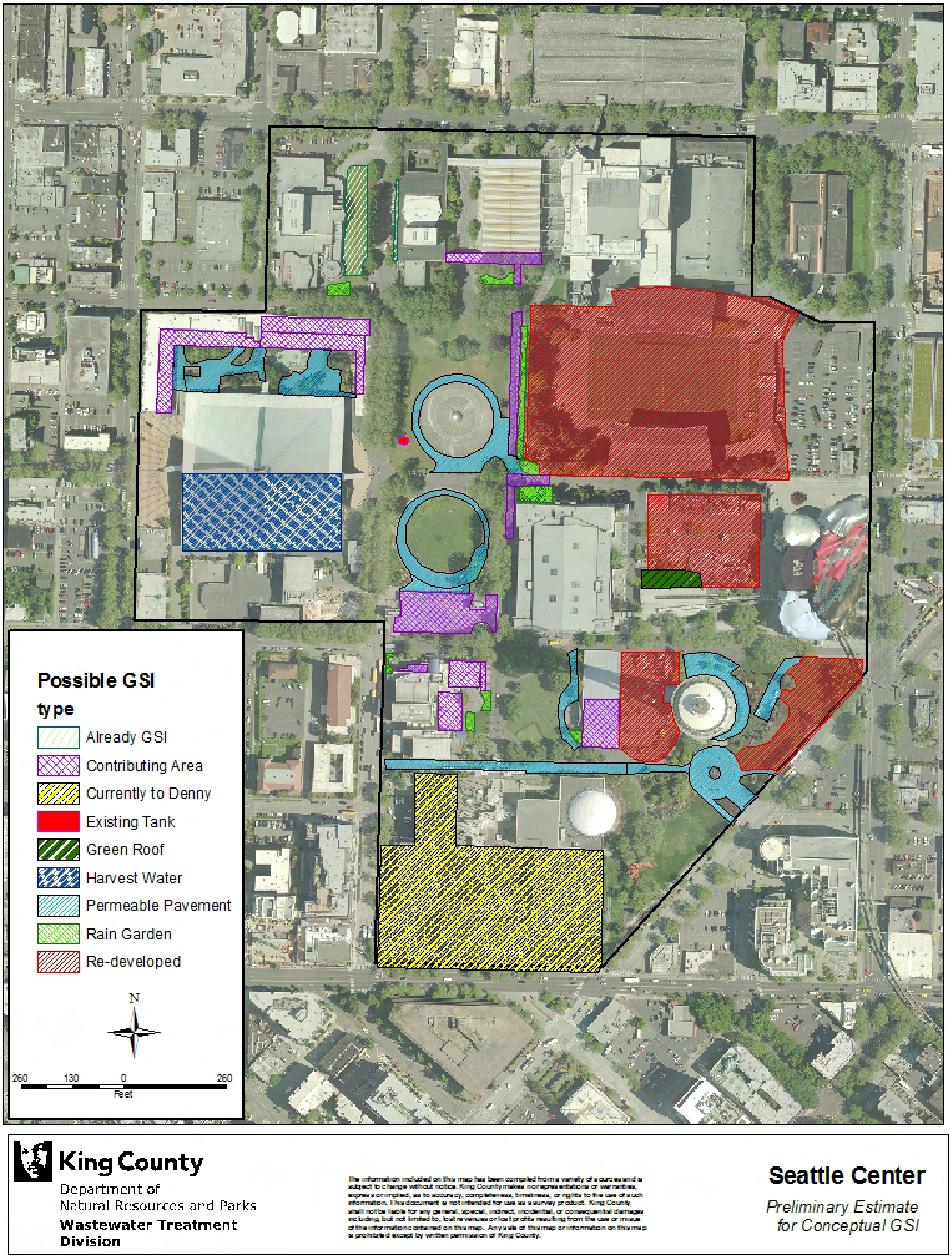
Figure 2 - A hydrograph of a portion of a September 1996 storm showing the flow before and after the GSI was added



Pacific Science Center is beginning a sustainability study focused on reducing, hopefully to zero, their stormwater discharge by implementing ideas similar to the Seattle Center's options of storm water harvesting for water feature make-up water, on-site infiltration through bio-retention and permeable pavement green roofs. Preliminary scoping indicates that the Science Center's non-potable water program could incorporate the Seattle Children's Theater roof capacity as part of their system. King County will continue to develop a model of the Seattle Center Campus in EPA SWMM to provide King County modeling staff with approximate volume reductions for verifying flow control.

As part of a memorandum of agreement (MOA) being negotiated with Seattle Center the CSO program will work closely with Seattle Center to implement projects to mitigate stormwater including bioretention, green roofs and permeable pavements. The King County CSO program will provide funding over the next eight years to cost-share in projects on Seattle Center Campus. The total funding is yet to be determined, but using the Commercial RainWise rebate of $6.00 per square foot mitigated, the approximate cost is $980,000 to be spent over eight years without cost-sharing. Maintenance would be performed by Seattle Center.

The equivalent storage pipe Tabula costs for 100,000 gallons would be $1.7 million construction and allied cost. Annual operations and maintenance costs for a storage pipe is estimated at $4,500 per year.


Possible GSI
type
Already GSI
Contributing Area
Currently to Denny
Existing Tank
Green Roof
Harvest Water
Permeable Pavement
Rain Garden
Re-developed
N
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Feet
King County
Department of
Natural Resources and Parks
Wastewater Treatment
Division
Seattle Center
Preliminary Estimate
for Conceptual GSI

Seattle Center Photos


Existing Bioretention at Theater Commons


Seattle Children's Theater potential bioretention area


Potential permeable pavement area


Potential permeable pavement area


South Fun Forest redevelopment – Chihuly Museum


Northwest Rooms plaza are potential permeable pavement

References

Crawford, Bruce. May 3, 2011. *Control of Dexter CSO Memorandum*. King County Department of Natural Resources and Parks, Wastewater Treatment Division

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