City of Richmond

GREELEY AND HANSEN

Richmond CSO Special Order by Consent

Water Quality Standards Coordination Process

TMDL Coordination Meeting No. 1

Workshop held at the

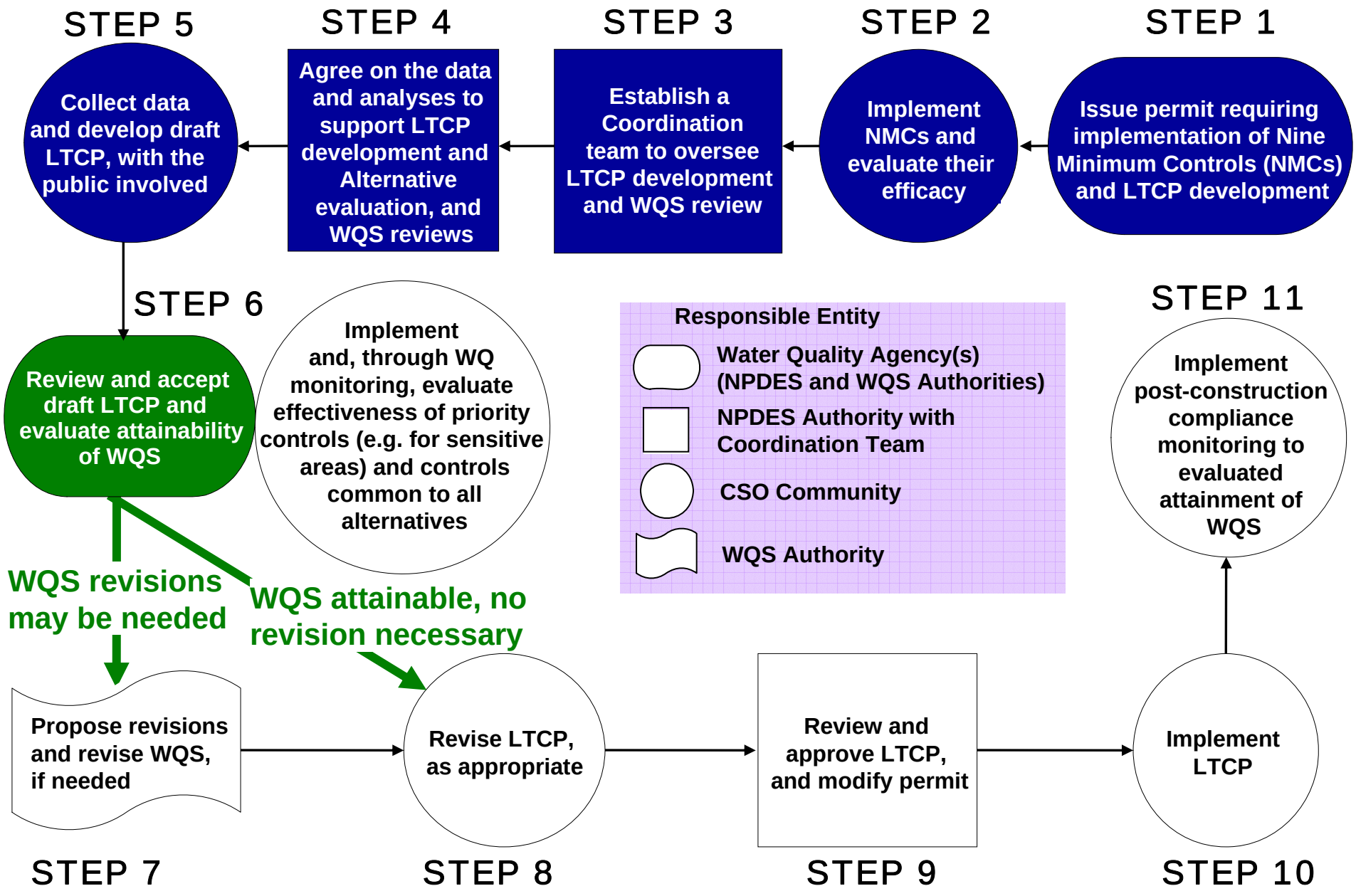
Department of Environmental Quality

April 4, 2006

Discussion Topics

- EPA Water Quality Standards Coordination Process
- Requirements of Special Order by Consent
- Phase II Performance
- LTCP Alternatives & Initial WQ Model Results
- Phase III Long Term Control Plan
- WQS Gap
- EPA Public Health Guidelines
- Geometric Mean and/or Single Sample Maximum
- WQ Model Results
  - E. Coli
  - Illness Rate
- Proposed Path Forward
- DEQ TMDL for Bacteria

Based on 1994 CSO Policy
Where are we in EPA's WQS coordination process?



Special Order by Consent

Requirements for Phase III CSO Controls

Special Order Requirement Number	Project Description
1	Disinfection Pilot Study
2	Phase III - Program Project Plan
3	Solids and Floatable Control for CSO Outfall No. 024
4	Solids and Floatable Control for CSO Outfall No. 026
5	Solids and Floatable Control for CSO Outfall No. 025
6	Fulton Bottom Urban Renewal Separation Project
7	Maury Street Separation Project
8	Orleans & Nicholson Street Separation Project
9	Peripheral In-Line Flow Equalization at Oakwood
10	Solids and Floatable Control for CSO Outfall No. 012
11	Solids and Floatable Control for CSO Outfall No. 014
12	Solids and Floatable Control for CSO Outfall No. 039
13	Lower Gillies Creek Conveyance
14	WWF at the WWTP: Solids Removal Improvements Project
15	WWF at the WWTP: Wet Weather Disinfection Facilities Project
16	WWF at the WWTP: Expand Secondary WWF Treatment Project
17	SRB: Adapt Existing Basin for Pass Through WWF Project
18	SRB: Shockoe Retention Basin 15 MG Expansion Project
19	SRB: Shockoe Wet Weather Disinfection Facility Project

Fixed Schedule

Subject to completion of EPA's WQS coordination process & based on the financial provisions of CSO Consent Special Order

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Phase I & II CSO Control Improvements

(Accomplishments to Date)

History

- 1950's Construction of WWTP & Interceptors
- 1970's First CSO Study
- 1983 Shockoe Retention Basin Completed
- 1985 VPDES Permit Addresses CSO's
- 1988 Comprehensive CSO Study
- 1992 Original Consent Order (Amended in 1996 & 1999)
- 2002 Completion of Phases I & II
- 2002 LTCP
- 2005 Phase III Consent Order
  - Schedule of projects
  - Water Quality Coordination Process
  - Affordability Criteria
- 2006 Program Project Plan

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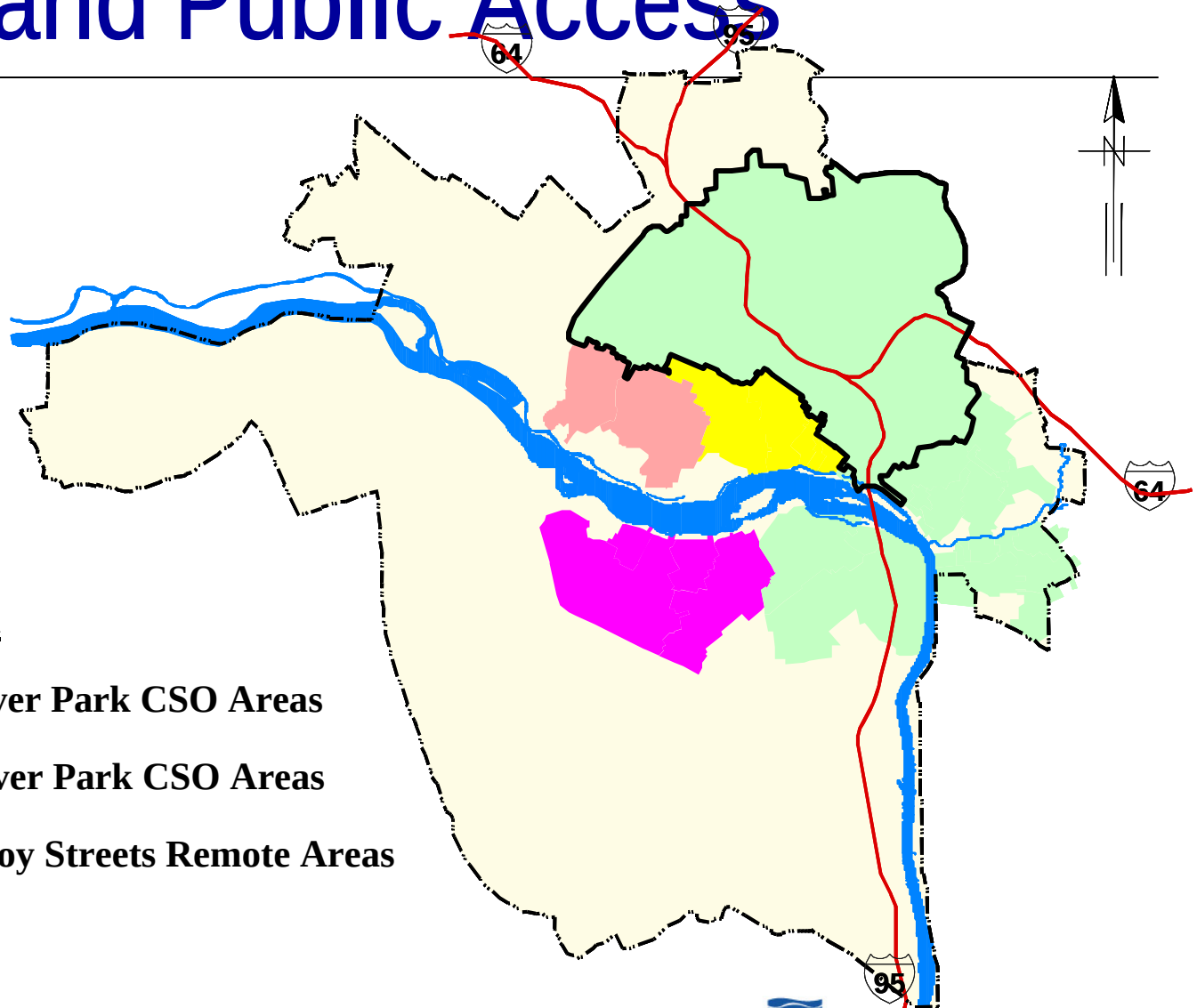
CSO Areas Associated with Parks and Public Access



Legend

- Southside James River Park CSO Areas
- Northside James River Park CSO Areas
- Hampton and McCloy Streets Remote Areas
- Other CSO Areas

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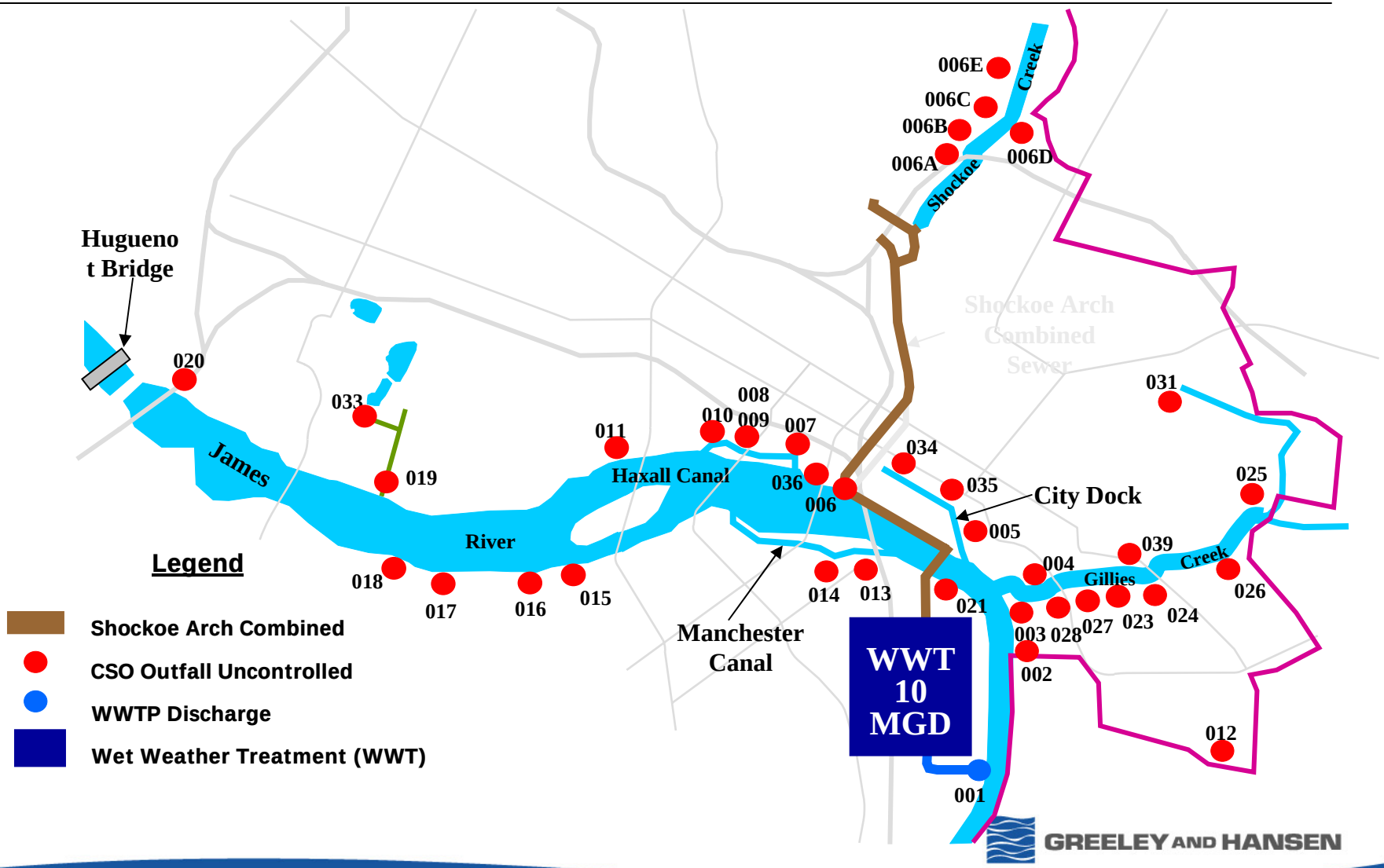
Location of Combined Sewer Overflow Points

City Prior to CSO Controls



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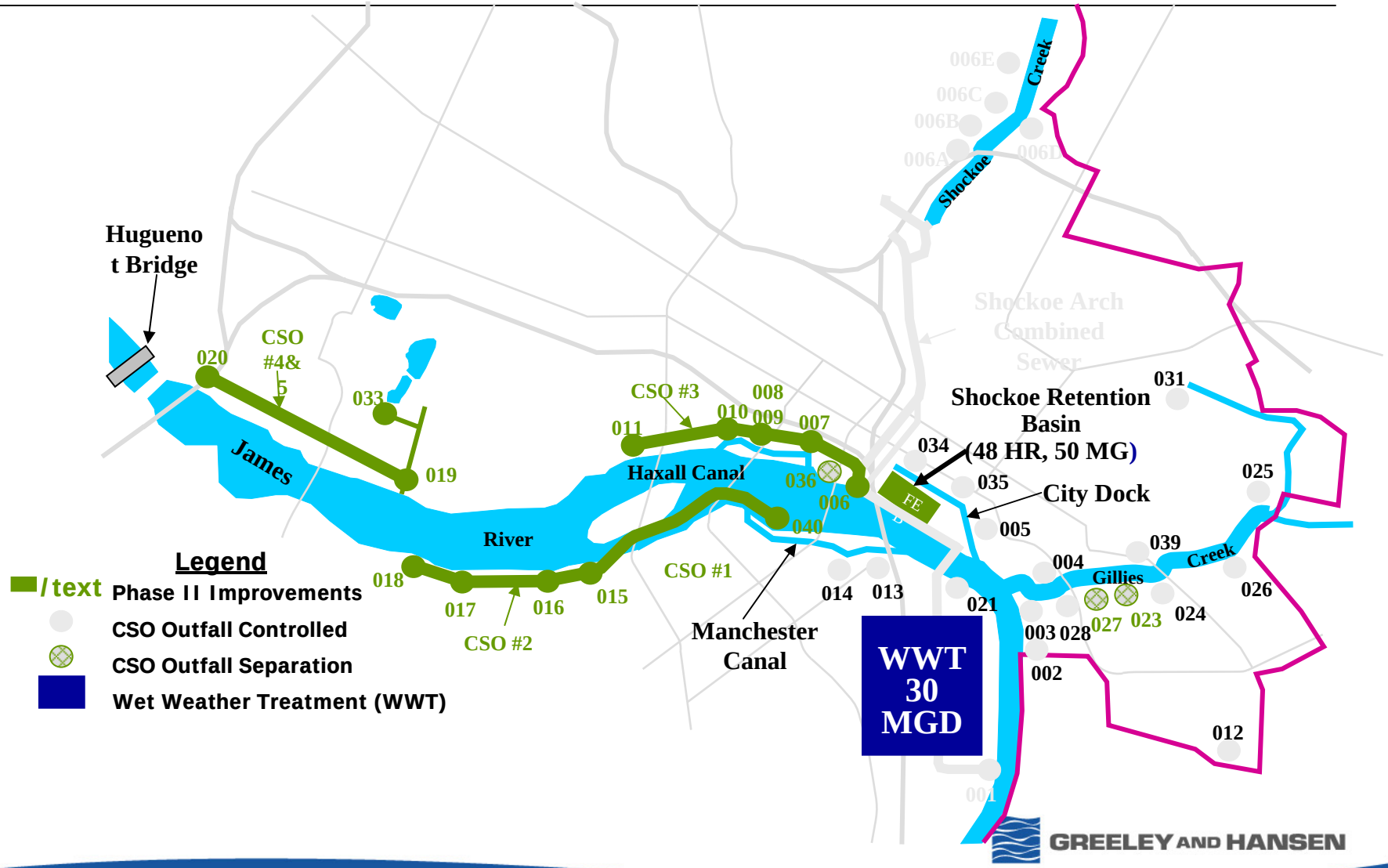
Richmond's CSO Control Plan

After Phase II Improvements



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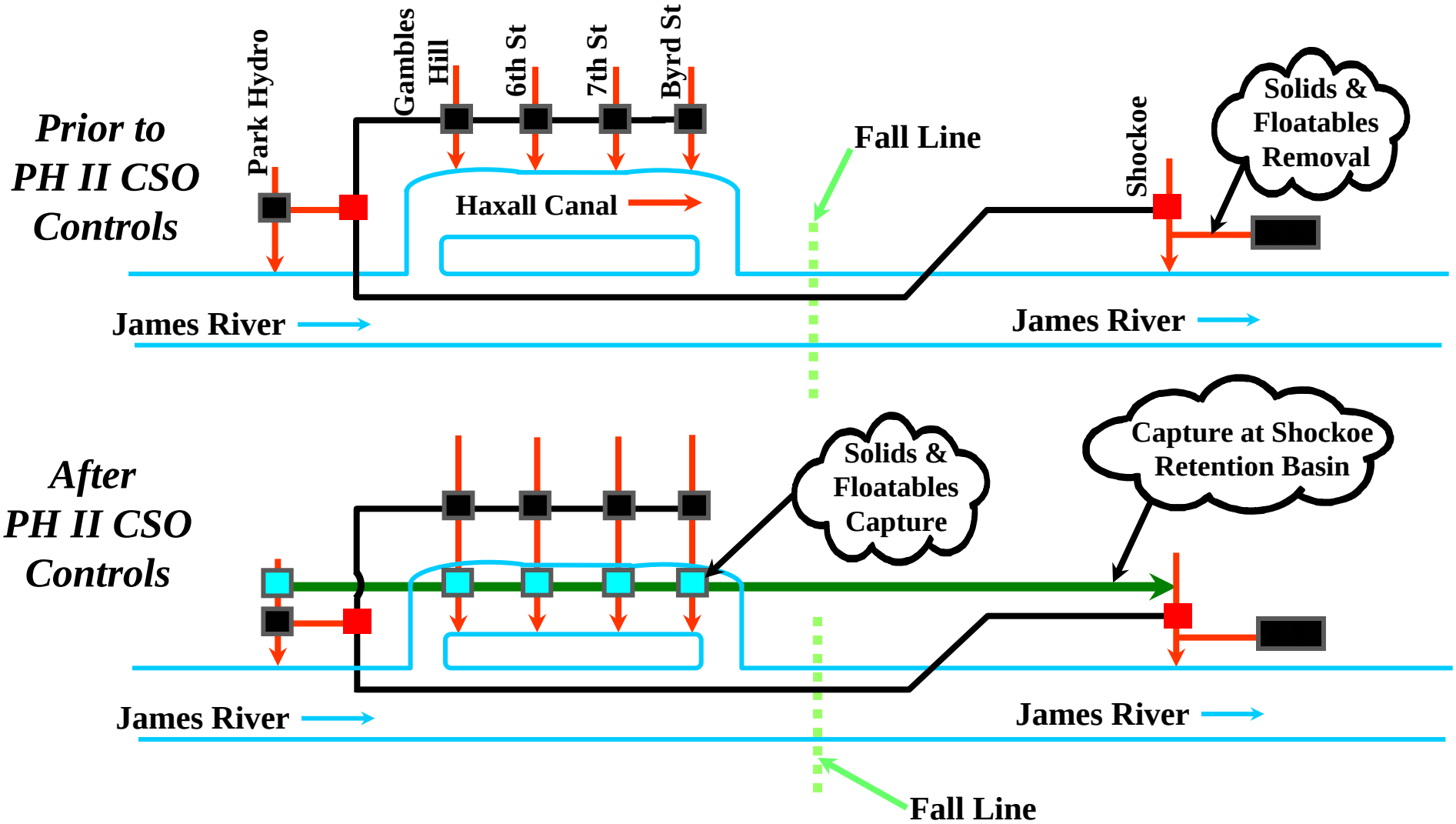
North Side James River CSO Controls



Performance

- Removes CSOs from sensitive areas
- Reduces CSO loads downriver
- Increases CSO treatment

Gambles Hill CSO Outfall

Prior to CSO Control (1996)

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Gambles Hill (July '99)

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Gambles Hill Performance

During Tropical Storm/ Hurricane Dennis (9/6/99)

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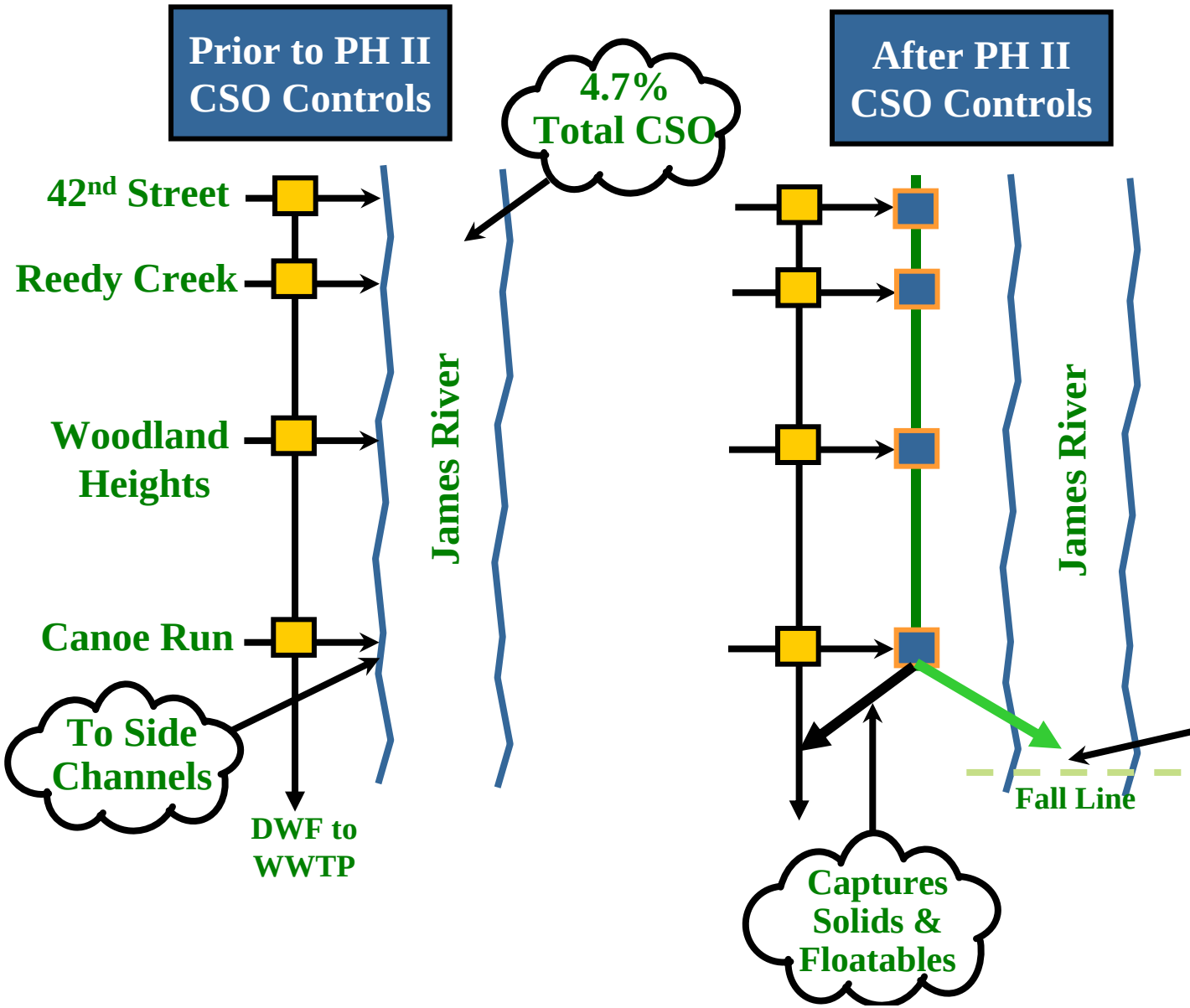
South Side James River CSO Controls



Performance

- Removes CSOs from sensitive areas
- Reduces CSO loads downriver
- Increases CSO treatment

42nd Street Regulator Performance

During Tropical Storm/ Hurricane Dennis (9/6/99)

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Canoe Run Performance

During Tropical Storm/ Hurricane Dennis (9/6/99)

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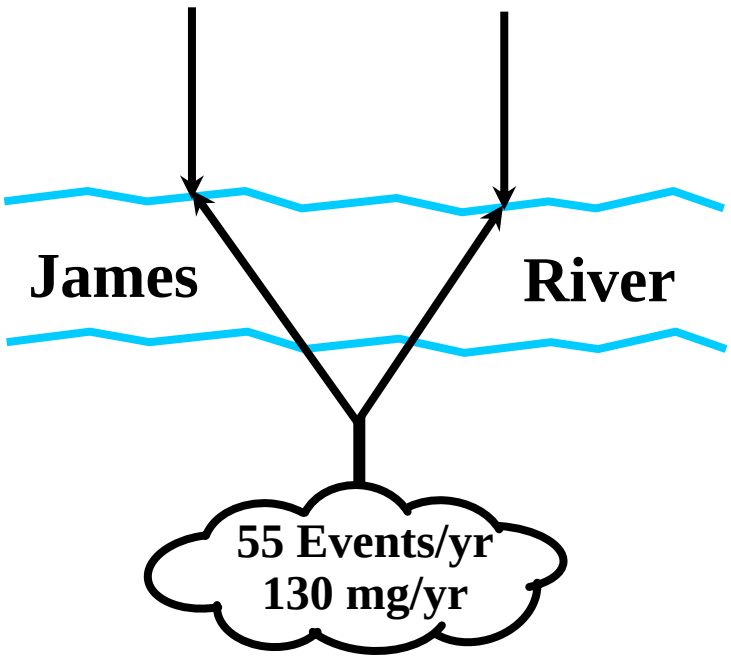
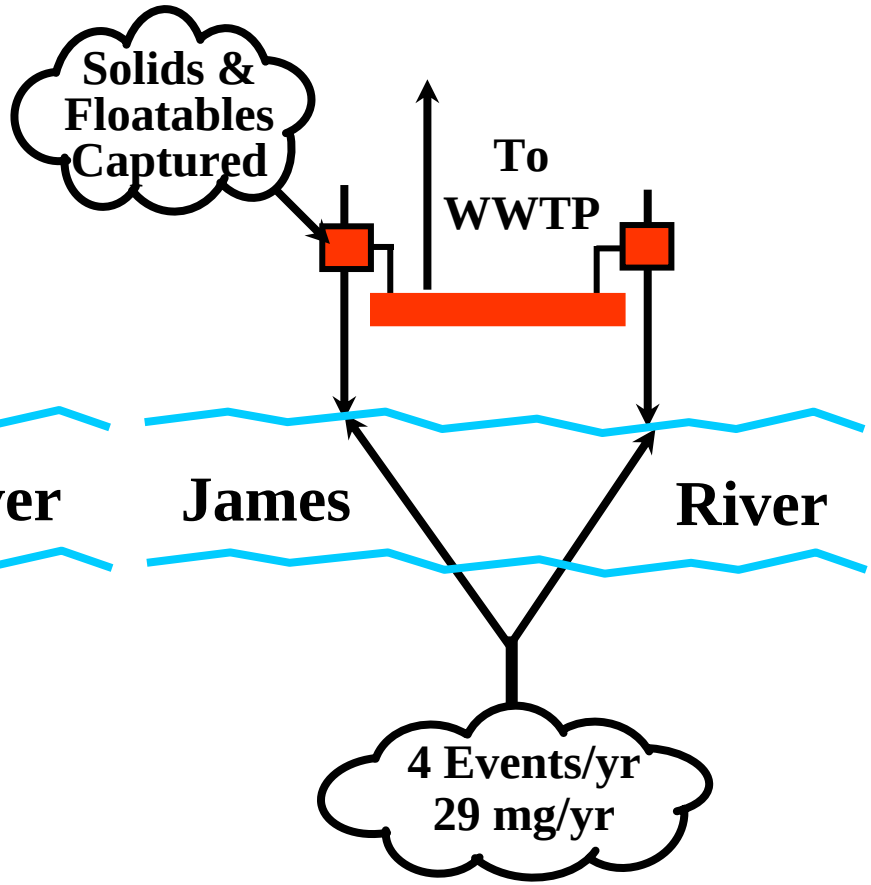
Retention CSO Controls

Prior to PH II CSO Controls



After PH II CSO Controls

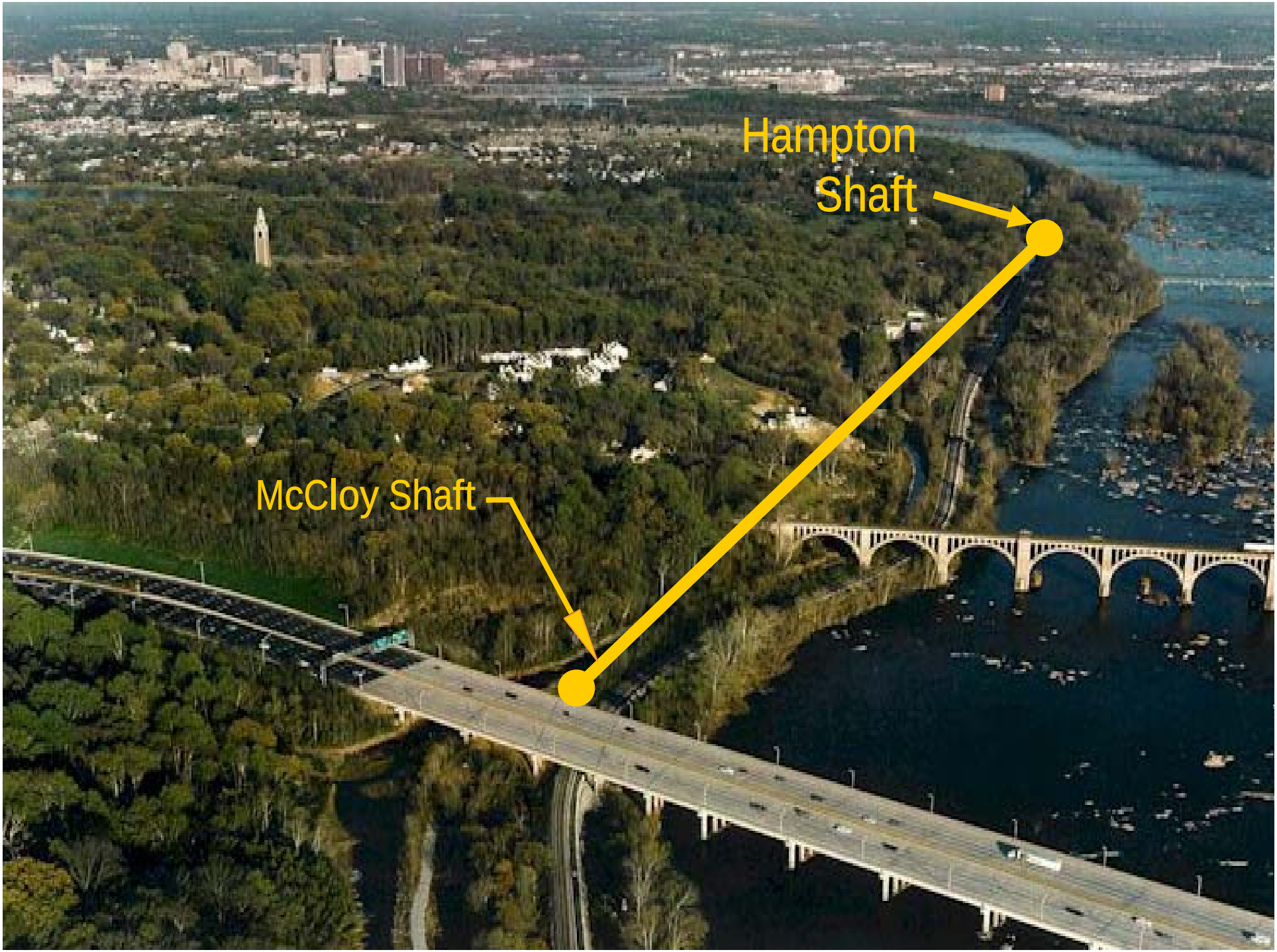


Performance

- Removes CSOs from sensitive areas
- Reduces CSO loads downriver
- Increases CSO treatment

4. 19. 2001

3. 2. 2000


Hampton
Shaft
McCloy Shaft

Richmond CSO Program Compliance

- The City Has Been Operating Under Successive Orders With the Board Since 1992
- For 15 Years the City Has Met & Exceeded All Its Commitments to DEQ

Local and National Recognition Earned by City's CSO Program

- Endorsement from the *Falls of the James Scenic River Advisory Committee* for City's CSO Program Special Order (June 14, 1999)

- *"Friend of the River Award"* from the James River Association (October 3, 1999)

- *1999 National CSO Control Program Excellence AWARD* from the USEPA

- Feature article in the 1999 September issue of "Civil Engineering Magazine"

Local and National Recognition Earned by City's CSO Program *(continued)*

- *Engineering Excellence Honor Award* from the Consulting Engineers Council of Illinois & American Consulting Engineers Council
- *Grand Conceptor Award* from the Virginia /American Council of Engineering Companies
- *Merit Award* from the American Society of Landscape Architects
- Featured in FHWA Transportation Enhancement – ISTEA First of a Kind Project

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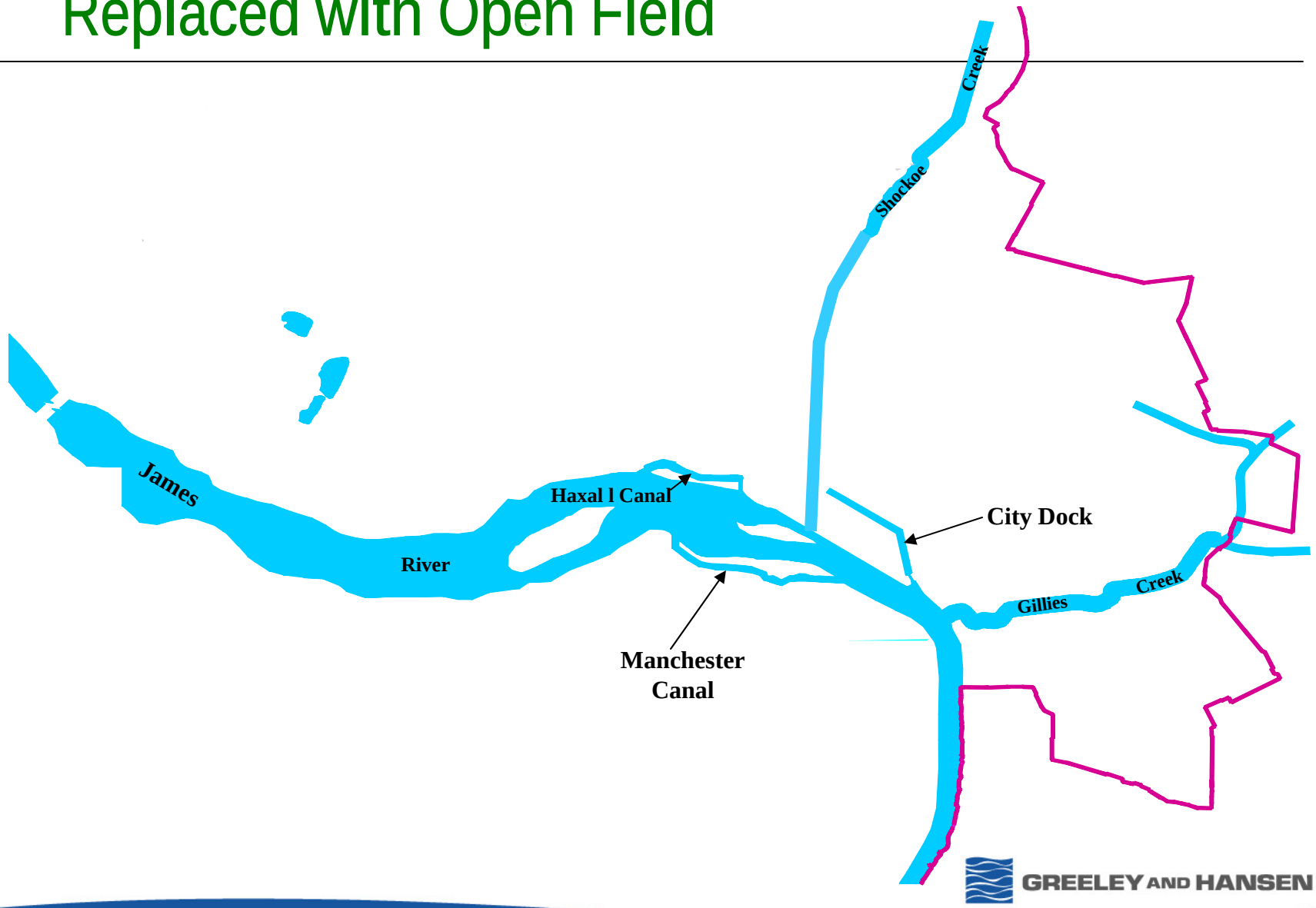
LTCP Alternatives & Initial Water Quality Model Results

Background A1 – Represents City Replaced with Open Field



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Water Quality Modeling Results – "No City"

"No City"

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	53	60	65	66	64	67	77	87	90	88	87	86	84	81	77	74	71	68	66	64
Feb	59	61	63	63	61	62	67	71	72	71	70	70	69	68	66	64	63	61	59	57
Mar	57	62	66	66	64	66	75	83	85	83	82	81	81	80	78	76	74	72	71	70
April	98	102	105	104	101	101	109	115	116	113	111	109	108	105	103	100	98	95	94	92
May	141	150	159	160	157	162	179	197	**202**	198	192	185	179	170	159	150	141	132	126	121
June	129	136	143	143	139	140	153	167	169	164	157	150	144	136	128	120	112	105	101	97
Jul	89	100	109	110	106	113	133	151	152	143	131	121	112	101	90	80	72	66	62	59
Aug	110	122	132	133	129	137	159	179	183	175	163	152	143	132	119	108	99	92	87	82
Sept	66	73	78	78	75	79	94	106	106	99	91	85	80	74	67	61	56	53	51	49
Oct	71	78	84	84	81	84	97	107	106	100	92	85	80	73	66	59	54	51	49	49
Nov	83	89	95	93	89	91	101	111	110	103	95	88	82	75	69	62	57	53	51	49
Dec	67	75	83	85	83	87	101	115	119	118	117	115	115	112	107	101	96	91	88	84

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	8	8	10	9	9	9	12	15	17	16	15	14	13	13	13	12	12	12	11	11
Feb	13	13	13	13	13	13	14	17	17	16	16	15	15	15	14	14	14	13	13	13
Mar	14	15	16	15	15	15	17	20	21	20	19	19	19	18	18	18	18	17	16	16
April	19	19	20	19	19	19	20	22	22	21	21	20	19	18	18	18	17	17	17	17
May	24	24	24	24	23	23	25	28	28	27	27	25	24	22	21	20	19	19	18	17
June	20	21	23	23	23	22	26	28	30	29	29	28	27	25	23	23	22	21	20	20
Jul	16	16	18	18	17	19	23	27	27	26	24	22	20	16	14	13	12	11	9	9
Aug	20	21	23	23	22	24	29	33	33	31	28	25	24	23	22	20	17	15	14	13
Sept	14	15	15	14	13	14	19	21	23	22	20	19	17	17	16	13	13	11	10	9
Oct	17	17	18	17	17	17	20	24	25	25	23	22	22	20	17	15	14	14	14	13
Nov	20	20	20	19	18	17	19	22	21	19	18	15	15	15	13	11	11	9	9	9
Dec	17	18	18	18	18	18	21	24	24	24	23	23	22	21	19	19	19	17	16	15

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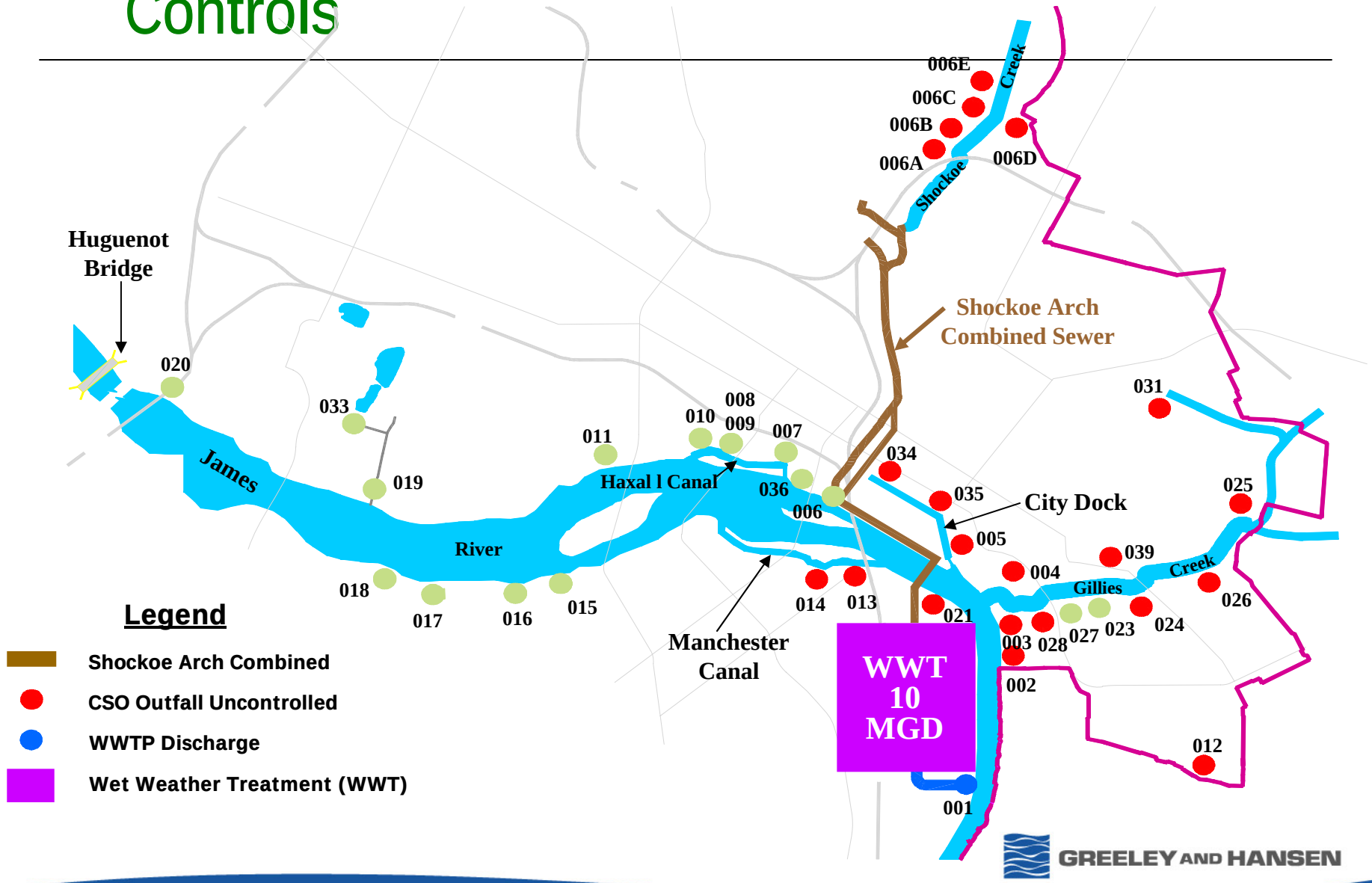
Background A2 – City Prior to CSO Controls



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Water Quality Modeling Results – "No CSO Control"

"No CSO Controls"

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	172	199	206	204	199	199	209	220	220	217	214	212	211	208	203	198	192	185	179	173
Feb	123	140	146	146	145	147	155	163	162	157	154	151	148	145	141	138	134	130	127	123
Mar	149	175	181	184	185	193	211	225	228	224	220	218	216	211	204	197	191	184	178	171
April	165	177	181	181	178	179	187	193	193	190	187	184	181	177	173	169	165	160	157	154
May	364	420	440	439	428	423	436	448	439	417	394	370	348	324	302	281	262	245	231	218
June	281	318	334	334	326	328	346	365	364	351	336	321	309	294	279	265	250	238	228	218
Jul	503	568	573	547	514	491	490	490	467	430	396	365	339	311	283	259	238	220	205	191
Aug	797	919	949	915	858	810	788	769	719	653	591	536	493	449	409	375	346	322	303	286
Sept	353	410	421	404	386	381	395	408	396	366	339	316	297	275	249	224	204	190	179	168
Oct	260	284	279	261	240	226	229	232	221	205	188	174	164	152	138	128	117	109	104	99
Nov	451	494	475	437	395	359	337	319	290	257	228	203	183	165	149	135	122	112	104	97
Dec	263	320	350	363	365	372	398	422	423	415	406	399	393	383	370	356	340	324	307	290

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	30	32	33	33	32	32	33	35	35	35	34	35	35	34	34	32	32	32	32	32
Feb	27	28	29	29	28	29	30	32	32	32	31	30	30	29	28	27	27	27	26	26
Mar	32	34	34	34	34	34	36	39	40	39	39	38	37	37	36	35	35	33	33	32
April	29	30	30	29	30	30	31	33	33	32	32	31	30	29	28	28	27	27	27	27
May	43	46	47	47	47	46	48	50	50	50	49	47	45	43	41	39	37	36	35	33
June	38	40	41	41	42	42	44	46	47	47	47	46	46	44	42	42	41	40	39	38
Jul	48	50	52	51	49	48	49	51	50	48	45	44	42	39	37	35	31	30	28	27
Aug	55	56	59	59	59	60	62	63	63	61	60	58	54	51	47	45	44	43	39	39
Sept	40	43	44	43	45	46	47	49	50	48	45	41	38	37	35	33	32	30	29	28
Oct	36	37	38	38	37	35	37	39	39	38	37	35	34	33	30	29	27	26	24	23
Nov	46	48	48	48	48	47	47	46	45	43	41	39	36	32	29	25	23	20	19	18
Dec	41	44	45	45	46	47	48	51	51	50	50	51	51	50	50	50	49	47	44	42

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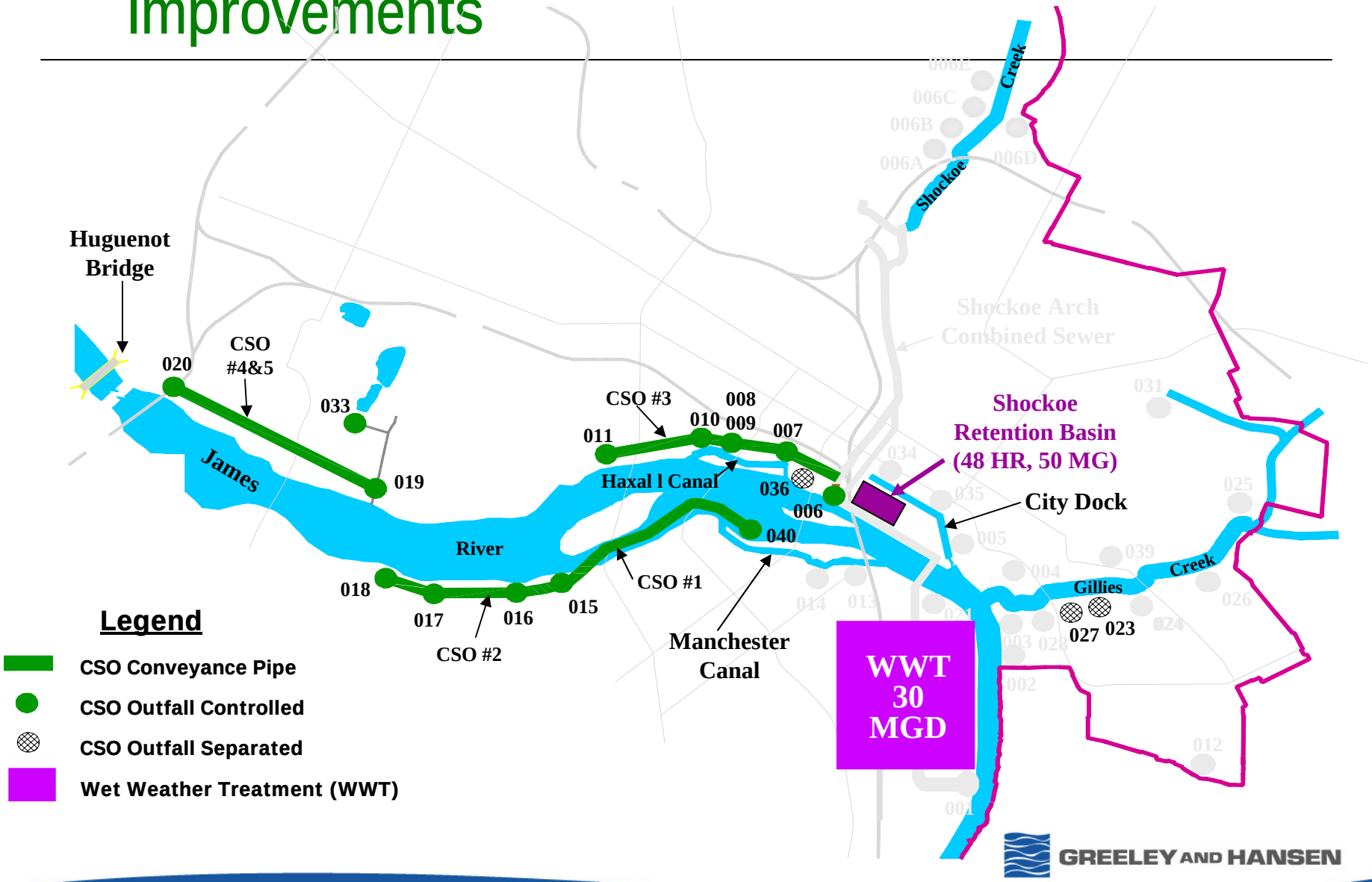
Background B – After Phase II Improvements



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Water Quality Modeling Results – Alternative B (Phase II Controls)

Alternative B - Phase II Controls

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	104	118	122	119	114	113	122	131	131	128	125	123	121	117	112	108	104	100	97	94
Feb	80	86	89	88	86	86	92	96	96	94	92	90	88	86	83	81	78	75	73	70
Mar	96	109	113	112	110	114	127	138	140	135	132	129	127	124	118	114	111	107	104	101
April	130	137	140	138	135	134	140	146	145	142	139	136	134	130	127	124	121	117	115	113
May	205	228	241	240	234	235	252	269	269	259	247	235	222	208	194	181	169	158	150	143
June	187	207	218	217	211	212	228	243	244	236	225	215	206	196	184	174	163	154	147	142
Jul	247	275	280	270	254	250	266	279	274	255	236	220	206	191	174	160	148	138	131	124
Aug	400	458	479	464	436	421	432	442	427	394	360	329	306	281	256	235	217	205	195	185
Sept	164	185	191	183	173	177	196	213	214	201	187	177	169	157	144	131	121	115	111	107
Oct	166	182	184	174	161	155	163	172	166	155	143	133	126	117	106	97	90	83	80	77
Nov	183	196	192	177	160	151	153	157	150	136	123	111	101	92	83	75	69	64	61	58
Dec	150	180	197	201	199	203	220	238	240	235	229	224	221	214	205	195	185	175	167	158

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	19	20	21	20	20	20	22	24	24	24	23	22	22	21	21	21	20	20	19	19
Feb	17	18	19	18	18	18	18	20	20	19	18	17	17	16	16	16	16	15	15	15
Mar	22	24	26	25	25	25	27	30	30	29	27	26	27	26	25	25	25	24	23	22
April	25	26	26	25	24	24	24	26	25	25	24	24	23	22	21	21	21	20	21	20
May	30	31	32	32	31	32	34	37	37	36	36	34	33	30	28	26	24	23	22	21
June	28	31	32	33	33	33	35	36	37	36	36	35	35	34	31	30	29	28	27	26
Jul	32	34	35	34	33	33	35	37	37	36	35	34	32	31	29	27	26	24	22	21
Aug	41	45	47	47	46	45	47	48	46	44	42	40	38	37	36	33	32	30	29	28
Sept	27	30	30	29	29	30	33	34	33	32	31	31	30	29	27	26	24	22	20	19
Oct	30	31	32	32	30	29	31	34	34	32	31	30	29	27	24	22	21	20	19	18
Nov	30	32	32	30	28	26	26	28	28	26	23	19	19	18	17	15	15	14	13	13
Dec	31	32	33	34	34	34	35	38	38	38	38	38	38	37	36	36	34	32	30	29

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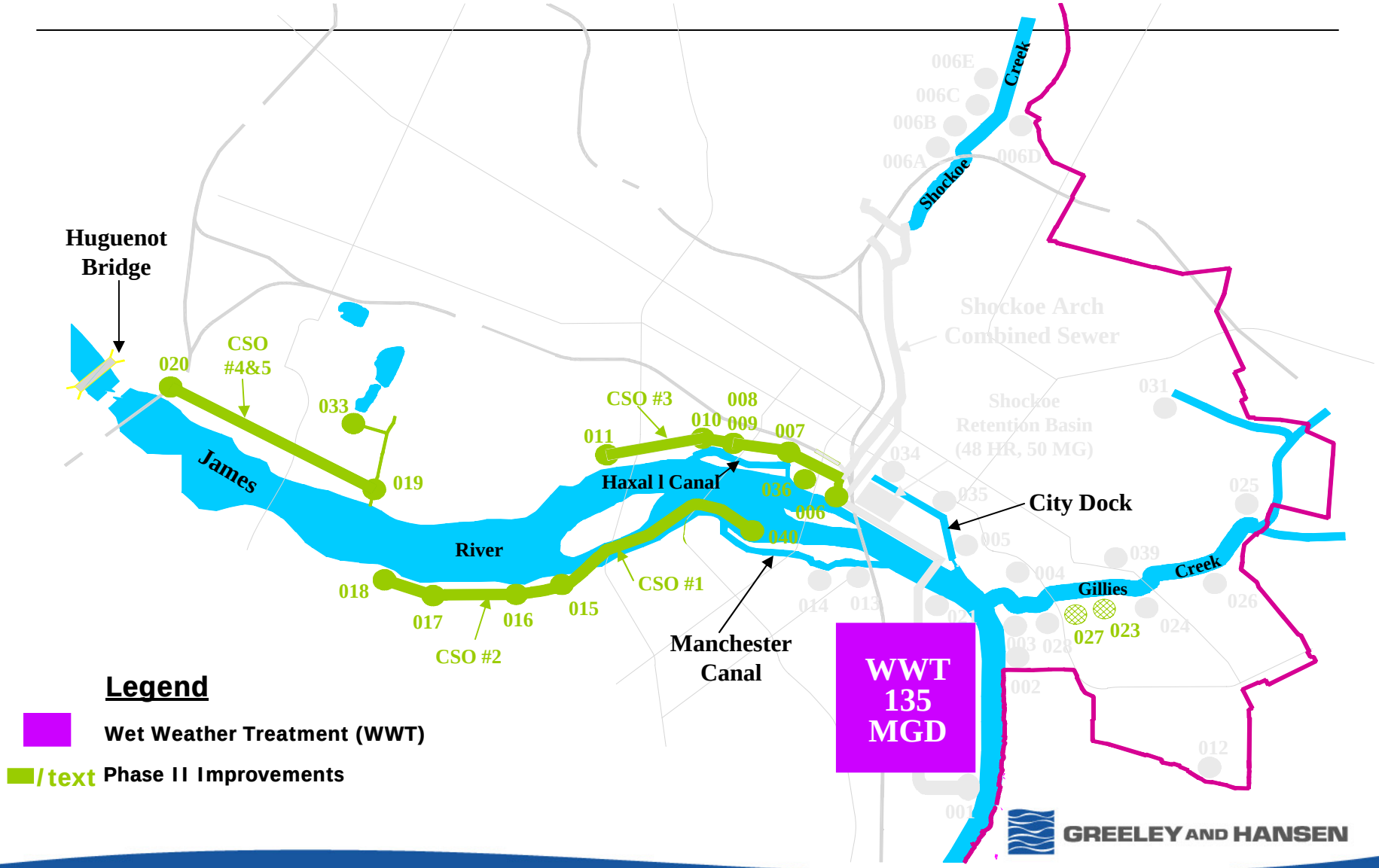
Alternative C - Maximize CSO Wet Weather Flow Treatment



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Water Quality Modeling Results – Alternative C

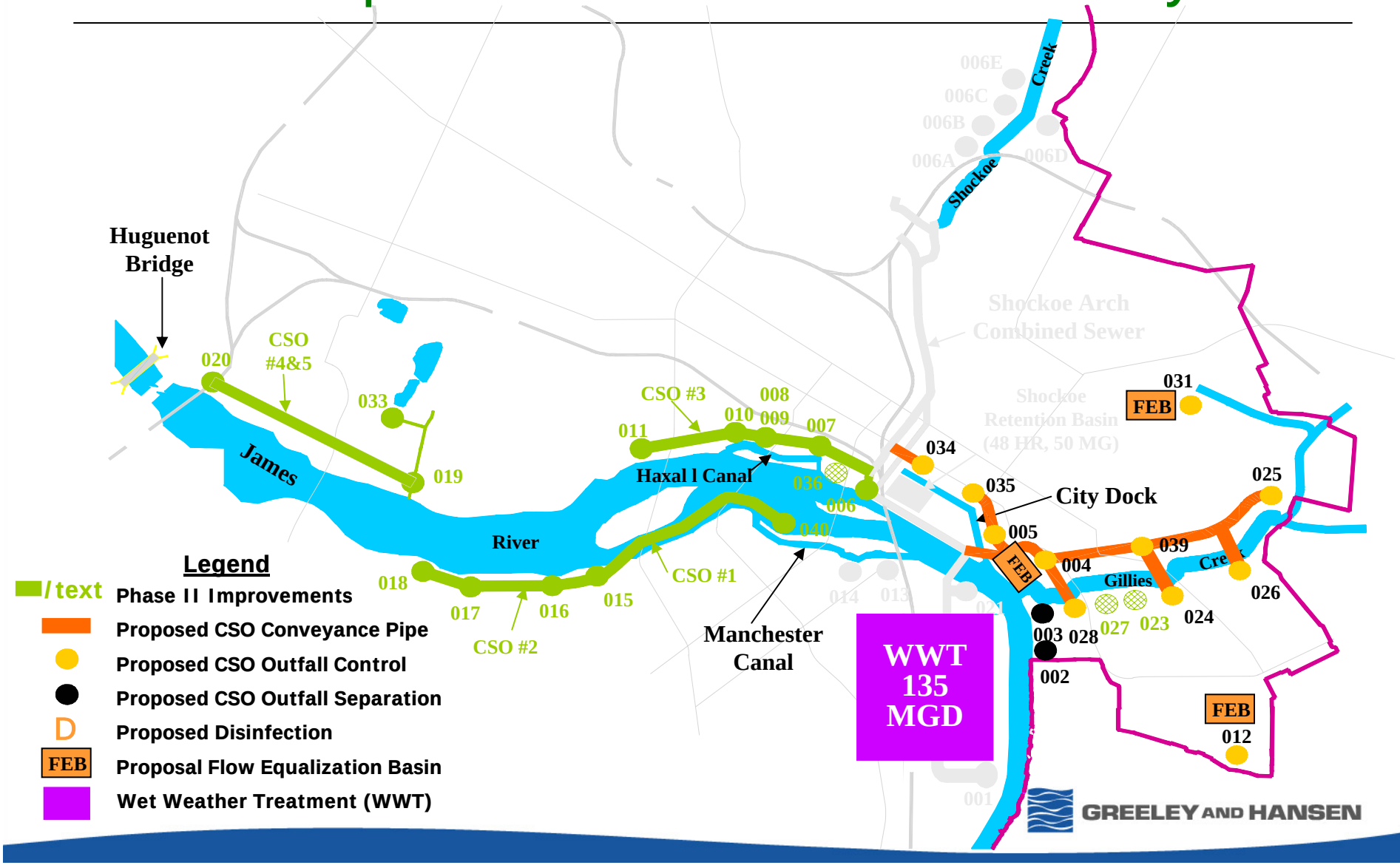
Alternative C

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	85	98	103	101	98	98	107	115	116	113	111	109	107	103	99	95	91	87	84	82
Feb	72	78	81	80	78	79	84	88	88	86	84	83	81	79	77	75	72	70	68	66
Mar	81	94	99	98	95	99	110	120	122	119	116	113	112	109	105	102	99	95	93	91
April	124	130	133	131	128	127	133	139	139	135	133	130	128	125	122	119	116	113	111	109
May	189	210	223	223	217	219	237	253	254	244	233	221	209	196	182	169	158	147	140	134
June	176	195	206	206	200	201	216	232	233	225	215	205	197	187	175	165	155	147	140	135
Jul	220	245	251	241	226	223	240	254	250	232	215	200	188	173	158	145	133	124	118	111
Aug	364	418	440	426	401	389	402	415	402	372	341	312	290	266	243	223	205	193	183	174
Sept	138	156	163	156	149	153	172	189	191	179	168	159	153	143	131	120	111	105	102	98
Oct	143	159	163	155	143	139	148	157	152	142	131	122	115	107	97	89	82	76	73	71
Nov	140	152	153	143	130	125	131	138	134	123	112	102	93	86	78	71	65	60	58	56
Dec	118	143	158	161	159	163	179	194	197	192	187	183	180	174	166	157	149	141	134	128

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	15	17	18	18	17	16	18	20	21	20	20	19	18	18	17	17	16	15	14	14
Feb	16	16	17	17	16	16	17	18	19	18	17	17	16	16	16	15	15	15	15	14
Mar	19	21	23	22	23	23	24	27	27	26	25	24	24	23	23	23	22	22	21	20
April	24	24	24	23	23	23	24	25	24	24	24	24	22	22	21	21	21	20	20	20
May	29	30	31	30	30	30	32	35	35	34	34	32	31	28	26	24	23	22	22	20
June	27	29	31	32	32	32	34	35	36	35	35	35	34	32	30	29	28	27	26	25
Jul	30	33	34	33	32	32	33	36	36	34	33	32	31	29	27	25	24	22	20	19
Aug	40	43	46	46	45	44	46	46	45	42	41	39	38	36	34	33	31	29	28	26
Sept	23	26	27	26	26	27	30	30	31	31	29	29	28	25	24	23	20	19	18	18
Oct	27	28	29	29	28	28	29	32	32	31	30	29	26	25	23	21	20	19	18	18
Nov	26	27	28	26	25	24	25	27	25	22	21	18	18	17	15	14	14	12	11	11
Dec	26	28	29	30	31	30	32	34	34	34	34	34	33	32	31	30	28	27	24	24

GREELEY AND HANSEN

Alternative D - North Side & Peripheral Flow Equalization & Gillies Creek Conveyance



Water Quality Modeling Results – Alternative D

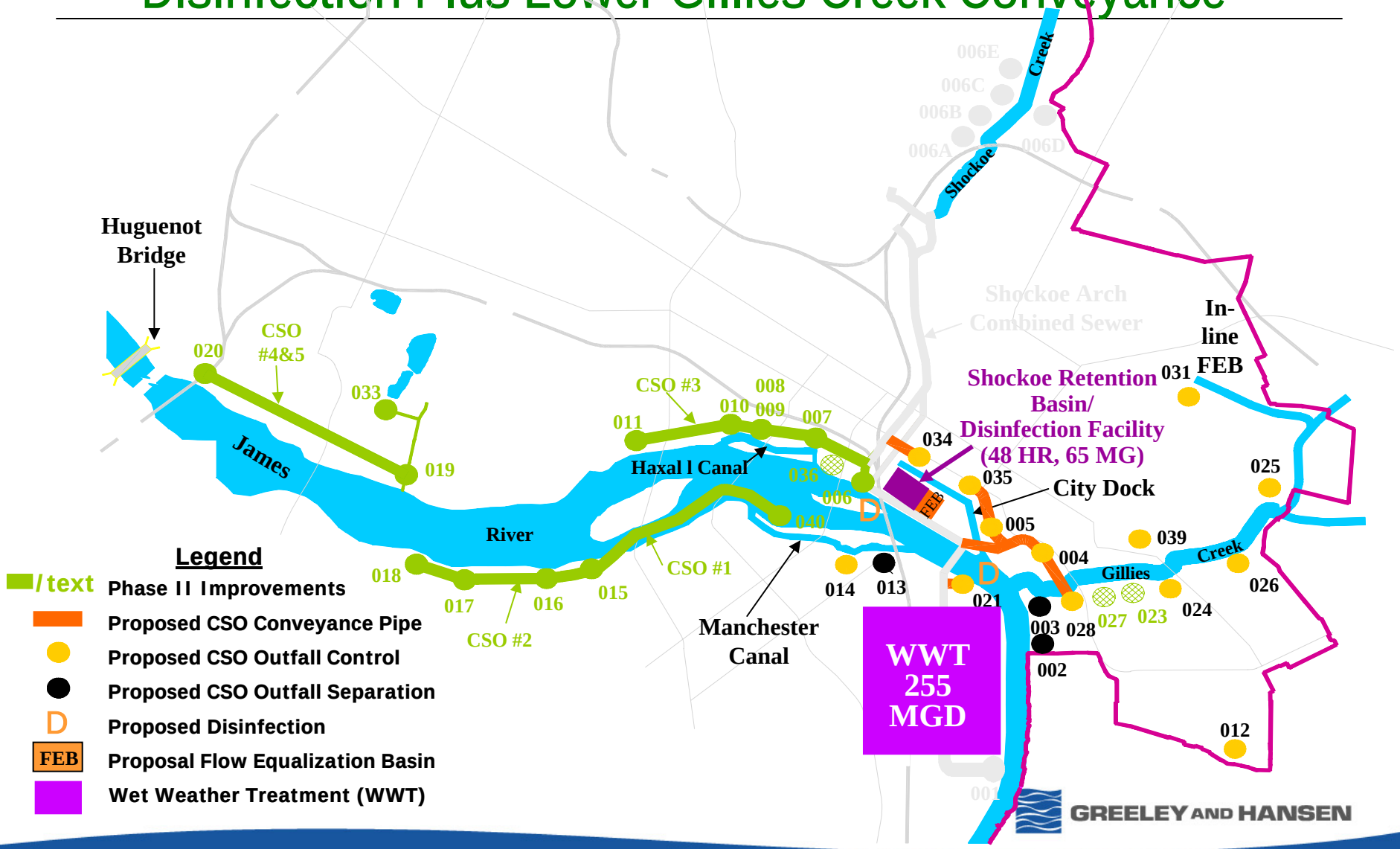
Alternative D

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	78	90	95	93	90	90	99	108	109	106	104	101	99	95	91	87	84	80	77	75
Feb	69	76	78	77	75	76	81	85	85	83	81	80	78	76	74	72	69	67	65	63
Mar	76	87	91	90	87	90	101	110	112	109	106	104	103	100	96	93	90	87	85	82
April	119	124	127	124	121	121	127	132	132	129	127	124	123	120	117	114	111	108	106	104
May	176	195	206	206	201	203	220	237	238	229	219	207	197	184	171	160	149	140	133	127
June	158	172	181	180	175	176	191	205	207	200	192	183	176	167	157	149	140	132	126	121
Jul	173	190	196	189	178	178	195	210	208	194	179	166	155	142	128	116	106	98	93	88
Aug	277	314	328	318	299	294	311	327	322	300	276	254	237	218	199	182	167	157	148	141
Sept	114	127	132	126	120	124	141	157	158	150	141	133	129	121	112	103	95	90	88	85
Oct	124	137	140	133	123	120	129	138	134	126	116	108	102	94	85	78	71	67	64	63
Nov	123	133	134	126	115	112	120	127	124	115	105	96	89	82	74	68	62	58	56	54
Dec	104	126	139	141	139	141	156	170	172	168	163	159	156	150	142	134	126	119	113	108

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	13	15	16	15	14	14	16	19	20	19	18	18	17	16	16	15	15	14	13	13
Feb	15	15	16	15	15	14	15	18	17	17	17	16	16	15	15	15	15	14	14	14
Mar	18	20	21	21	21	21	23	25	25	24	23	22	22	22	21	21	20	20	19	18
April	23	24	23	23	22	22	23	24	24	23	23	23	22	21	21	20	20	20	20	20
May	28	28	29	29	28	29	31	34	33	32	31	30	28	26	24	22	21	21	21	20
June	24	26	28	28	28	29	32	33	34	34	34	33	32	30	27	27	26	24	24	24
Jul	28	30	30	30	28	29	31	34	33	32	30	30	28	27	25	22	20	19	18	17
Aug	36	38	41	40	38	38	42	43	42	40	38	37	34	32	30	29	26	25	24	22
Sept	21	23	24	23	23	23	26	28	29	28	27	25	24	22	22	20	19	17	17	15
Oct	24	26	28	26	26	25	26	30	30	30	28	27	26	25	22	20	19	19	18	17
Nov	24	26	26	25	23	23	22	25	24	22	20	17	17	17	15	13	12	11	10	11
Dec	23	26	27	28	28	27	30	32	32	31	31	30	29	28	26	25	24	23	21	21

Alternative E - Increase CSO

WWF Treatment & Shockoe Expansion With Disinfection Plus Lower Gillies Creek Conveyance



Water Quality Modeling Results – Alternative E (Phase III Controls)

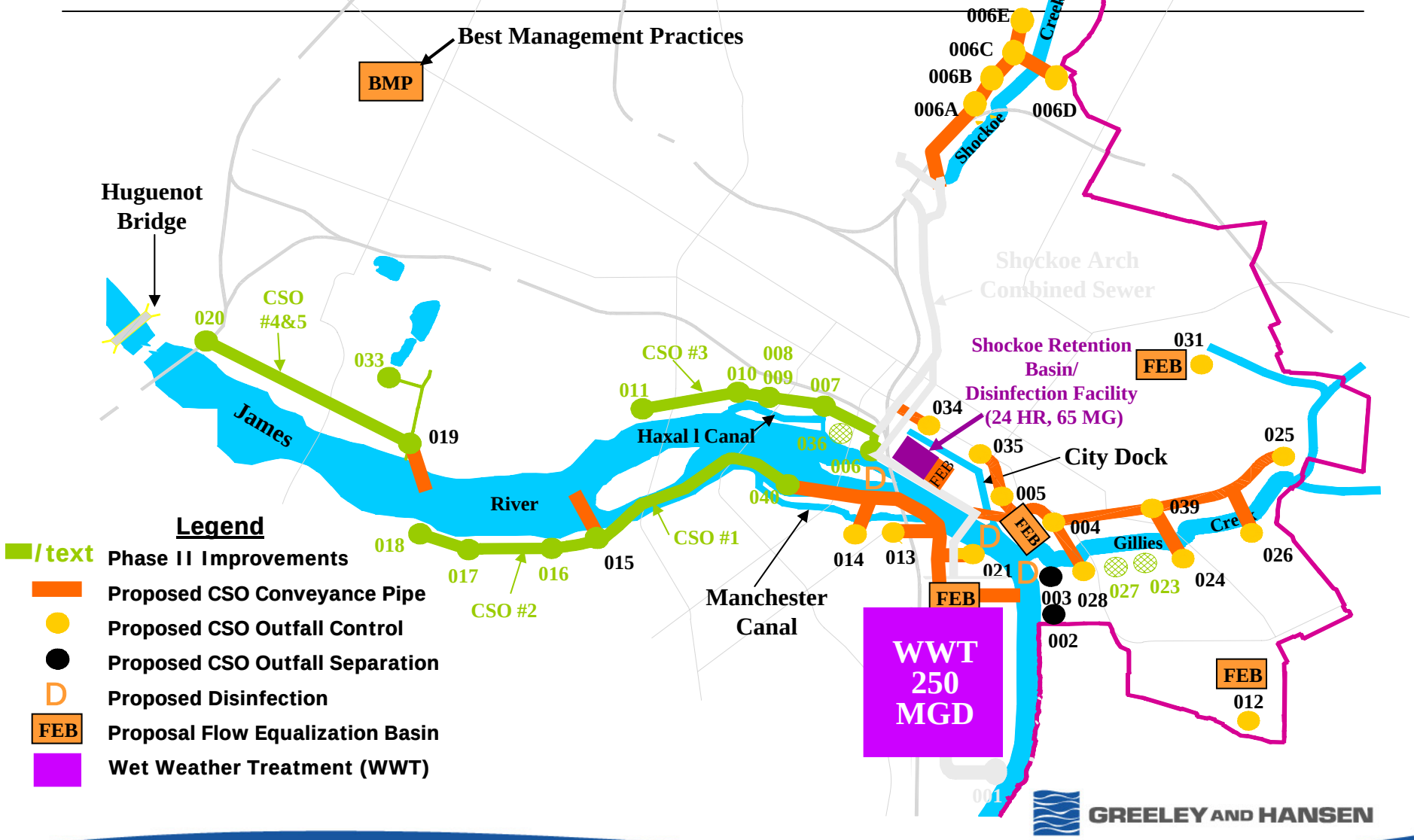
Alternative E - Proposed Phase III Controls

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	72	84	89	88	84	85	94	103	104	101	99	97	95	91	87	83	80	76	74	72
Feb	67	74	76	75	74	74	79	83	83	81	80	78	77	74	72	70	68	65	63	61
Mar	71	81	86	85	82	85	95	104	106	104	101	99	98	96	92	89	87	84	81	79
April	113	119	122	120	116	116	122	128	128	125	122	120	119	116	113	110	107	104	102	100
May	165	183	195	195	190	192	**209**	**226**	**228**	**220**	**211**	**200**	190	179	166	155	145	136	130	124
June	149	163	172	171	166	167	181	195	196	189	181	172	165	157	147	139	131	124	118	113
Jul	148	166	173	168	157	158	175	191	189	176	162	150	139	127	115	103	94	87	82	78
Aug	**218**	**251**	**267**	**260**	**244**	**242**	**260**	**277**	**275**	**257**	**237**	**219**	**205**	189	172	158	145	136	129	122
Sept	96	108	113	109	104	108	124	138	139	130	122	115	110	102	94	86	80	76	74	72
Oct	105	117	122	116	108	106	115	124	121	114	106	99	94	86	78	71	65	61	59	58
Nov	109	120	123	116	107	105	113	121	118	110	101	93	86	79	72	66	60	56	54	52
Dec	92	112	124	125	123	125	139	153	155	151	147	143	140	135	128	120	113	107	101	96

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	12	14	14	14	13	13	15	18	19	18	18	17	16	15	15	15	14	14	13	12
Feb	14	14	15	14	14	14	15	17	17	17	16	15	15	15	15	14	14	14	14	13
Mar	17	19	20	20	20	20	21	24	24	23	22	21	21	20	20	20	19	18	17	17
April	22	23	23	22	22	21	22	24	23	23	22	22	21	20	20	19	19	18	18	18
May	27	27	28	27	27	27	29	32	31	30	30	29	27	24	22	21	21	21	20	19
June	23	25	27	27	27	27	30	32	33	32	32	31	31	28	26	25	25	24	24	24
Jul	26	28	29	28	26	27	30	32	32	30	29	27	27	25	22	19	18	17	15	14
Aug	31	35	38	37	36	36	39	41	40	38	36	33	31	29	28	26	23	22	21	19
Sept	20	22	23	21	20	20	24	26	27	26	25	24	21	21	20	18	17	15	15	13
Oct	21	23	24	23	23	23	25	29	29	28	27	26	25	24	21	19	18	17	16	15
Nov	23	24	25	23	21	21	22	24	23	21	19	16	16	16	14	12	11	10	10	10
Dec	20	23	25	25	24	25	28	30	30	29	28	27	26	24	23	22	21	20	18	17

GREELEY AND HANSEN

Alternative F - Control CSOs to 4 Overflows Per Year



GREELEY AND HANSEN

Water Quality Modeling Results – Alternative F

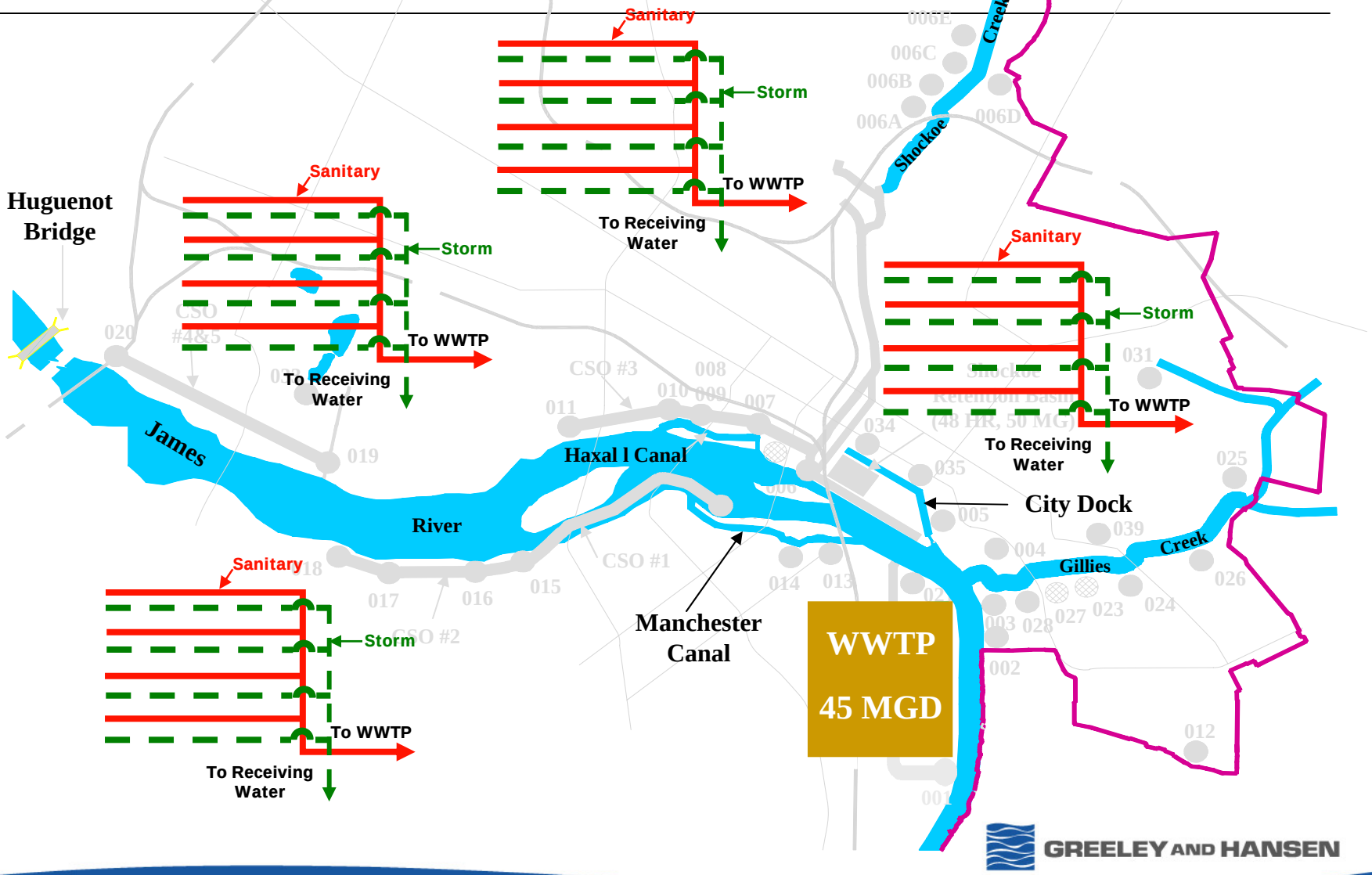
Alternative F

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	69	82	87	85	82	83	92	101	102	100	98	95	93	90	86	82	79	75	73	71
Feb	65	72	74	73	72	72	77	81	82	79	78	77	75	73	71	69	66	64	62	60
Mar	69	79	83	82	79	82	92	101	103	100	98	96	95	93	89	86	84	81	79	76
April	110	116	119	117	113	113	119	125	125	122	120	118	116	113	110	108	105	102	100	98
May	156	173	184	184	180	183	200	**217**	**219**	**212**	**204**	194	185	174	162	151	141	133	126	121
June	141	152	161	160	155	157	171	185	187	181	173	165	159	151	142	134	126	119	114	109
Jul	131	146	154	150	142	145	163	178	177	165	152	141	131	120	108	97	88	82	77	73
Aug	182	**209**	**223**	**219**	**208**	**210**	**230**	**250**	**251**	**238**	**220**	**204**	191	177	162	148	136	128	121	115
Sept	89	100	105	101	96	100	115	129	130	122	115	108	104	98	90	83	77	74	72	70
Oct	99	111	115	111	103	101	110	119	118	111	103	96	91	84	76	70	64	60	58	57
Nov	103	114	118	112	103	102	111	119	117	109	100	92	85	79	71	65	60	56	54	52
Dec	88	107	118	120	117	120	133	147	149	145	141	137	134	129	123	115	109	103	98	93

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	11	12	13	13	13	12	15	17	19	18	17	17	16	15	15	14	14	13	12	12
Feb	14	13	14	14	13	13	14	17	17	17	16	15	15	15	15	14	14	14	14	13
Mar	17	18	19	18	18	18	20	23	23	22	21	21	20	20	19	19	18	18	17	16
April	22	22	22	21	21	20	21	23	23	22	22	21	20	20	19	19	18	18	18	18
May	25	26	26	25	24	25	27	30	30	30	29	28	26	23	22	21	20	20	19	18
June	22	23	25	25	25	25	28	31	32	31	31	31	30	27	25	24	24	23	23	23
Jul	24	26	28	26	25	25	28	30	30	29	27	26	25	24	20	18	17	15	14	13
Aug	28	30	33	33	31	31	35	38	38	35	33	31	29	28	27	25	23	21	20	18
Sept	18	19	20	19	17	19	23	25	27	25	24	23	21	20	20	17	16	15	14	12
Oct	20	21	23	22	22	22	24	28	28	28	26	25	24	23	20	19	17	16	15	15
Nov	21	22	23	22	21	20	21	23	23	21	19	16	16	16	14	11	11	10	10	10
Dec	19	22	23	24	23	23	26	29	29	28	27	26	25	22	21	20	20	18	16	15

GREELEY AND HANSEN

Alternative G – Complete Citywide Sewer Separation



GREELEY AND HANSEN

Water Quality Modeling Results – Alternative G (Complete Separation)

Alternative G - Complete Separation

Description	FECAL COLIFORM -30 DAY GEOMETRIC MEAN (MPN/100ml)																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	75	82	86	86	84	86	96	106	108	105	102	99	96	92	87	82	79	75	72	70
Feb	70	73	74	74	72	73	78	83	83	81	80	79	77	75	73	71	69	67	64	62
Mar	75	80	83	83	80	82	91	99	101	98	96	94	93	92	89	86	84	81	79	77
April	116	120	122	120	117	116	123	129	130	126	124	121	119	115	111	107	104	100	98	95
May	188	**203**	**212**	**212**	**208**	**209**	**224**	**239**	**239**	**230**	**221**	**211**	**201**	189	176	165	153	143	135	129
June	168	179	183	181	174	173	184	196	196	188	178	169	162	153	143	134	125	118	112	107
Jul	144	158	163	158	148	148	166	180	177	163	148	135	124	112	99	89	80	73	69	65
Aug	172	185	189	182	170	170	188	**206**	**207**	197	183	171	162	150	137	125	115	108	103	99
Sept	107	115	116	111	104	106	119	129	126	116	105	97	91	83	75	68	62	58	55	53
Oct	111	118	121	117	109	109	121	131	128	119	109	101	95	87	78	71	64	60	58	56
Nov	116	122	123	117	109	107	116	124	122	113	105	97	90	82	75	68	62	57	54	51
Dec	100	112	119	121	119	123	138	151	154	150	145	140	137	131	124	116	109	102	96	91

Description	FECAL COLIFORM - PERCENT OF TIME GREATER THAN 400 MPN/100 mL																			
Model Segments	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
River Mile	98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Jan	**12**	**15**	**16**	**16**	**15**	**15**	**17**	**20**	**21**	**20**	**19**	**18**	**17**	**16**	**16**	**15**	**15**	**14**	**13**	**13**
Feb	**15**	**16**	**16**	**16**	**16**	**16**	**16**	**18**	**18**	**18**	**17**	**17**	**17**	**16**	**16**	**15**	**15**	**14**	**15**	**14**
Mar	**18**	**20**	**20**	**20**	**19**	**20**	**21**	**24**	**24**	**23**	**22**	**22**	**21**	**21**	**21**	**21**	**20**	**19**	**18**	**18**
April	**23**	**23**	**23**	**21**	**21**	**21**	**22**	**24**	**23**	**22**	**22**	**22**	**21**	**20**	**19**	**19**	**19**	**19**	**18**	**18**
May	**28**	**30**	**30**	**29**	**29**	**28**	**30**	**33**	**33**	**31**	**31**	**29**	**27**	**25**	**23**	**21**	**20**	**20**	**19**	**18**
June	**25**	**27**	**29**	**29**	**29**	**29**	**31**	**33**	**33**	**33**	**32**	**32**	**30**	**28**	**26**	**25**	**24**	**23**	**23**	**22**
Jul	**27**	**29**	**29**	**27**	**25**	**25**	**29**	**31**	**31**	**29**	**27**	**25**	**23**	**20**	**18**	**16**	**15**	**13**	**11**	**10**
Aug	**31**	**33**	**34**	**34**	**31**	**31**	**35**	**36**	**36**	**34**	**31**	**28**	**27**	**26**	**25**	**24**	**22**	**20**	**19**	**19**
Sept	**22**	**24**	**23**	**22**	**21**	**21**	**25**	**26**	**27**	**26**	**25**	**23**	**21**	**20**	**19**	**17**	**16**	**14**	**14**	**11**
Oct	**23**	**25**	**26**	**25**	**24**	**24**	**26**	**29**	**29**	**28**	**26**	**25**	**24**	**23**	**20**	**18**	**16**	**16**	**15**	**15**
Nov	**24**	**26**	**26**	**24**	**22**	**21**	**23**	**25**	**24**	**22**	**21**	**17**	**17**	**17**	**14**	**12**	**11**	10	10	9
Dec	**21**	**24**	**25**	**25**	**24**	**24**	**27**	**30**	**29**	**29**	**28**	**27**	**26**	**25**	**23**	**22**	**21**	**20**	**18**	**17**

GREELEY AND HANSEN

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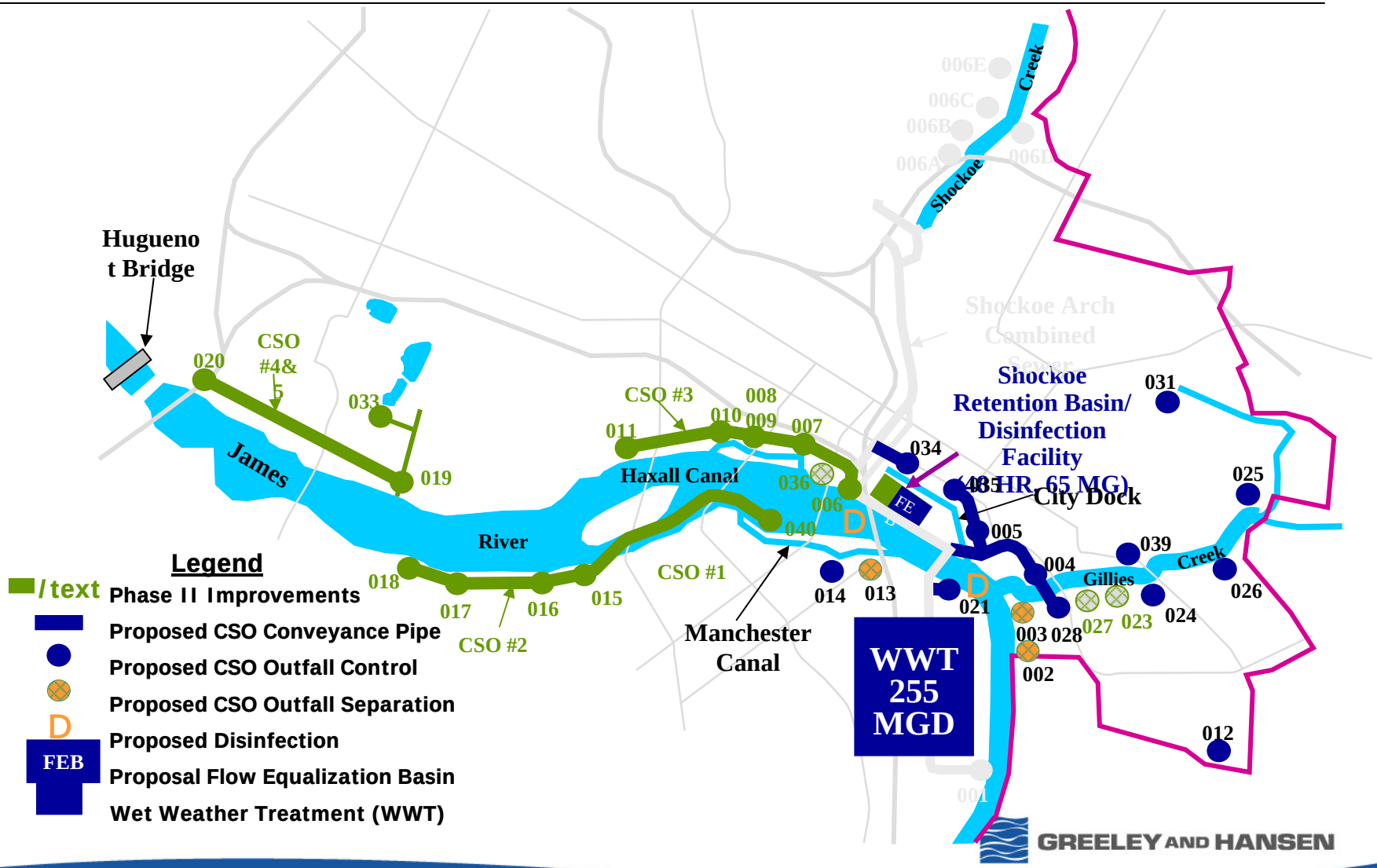
Phase III
Long-Term Control Plan

Alternative E

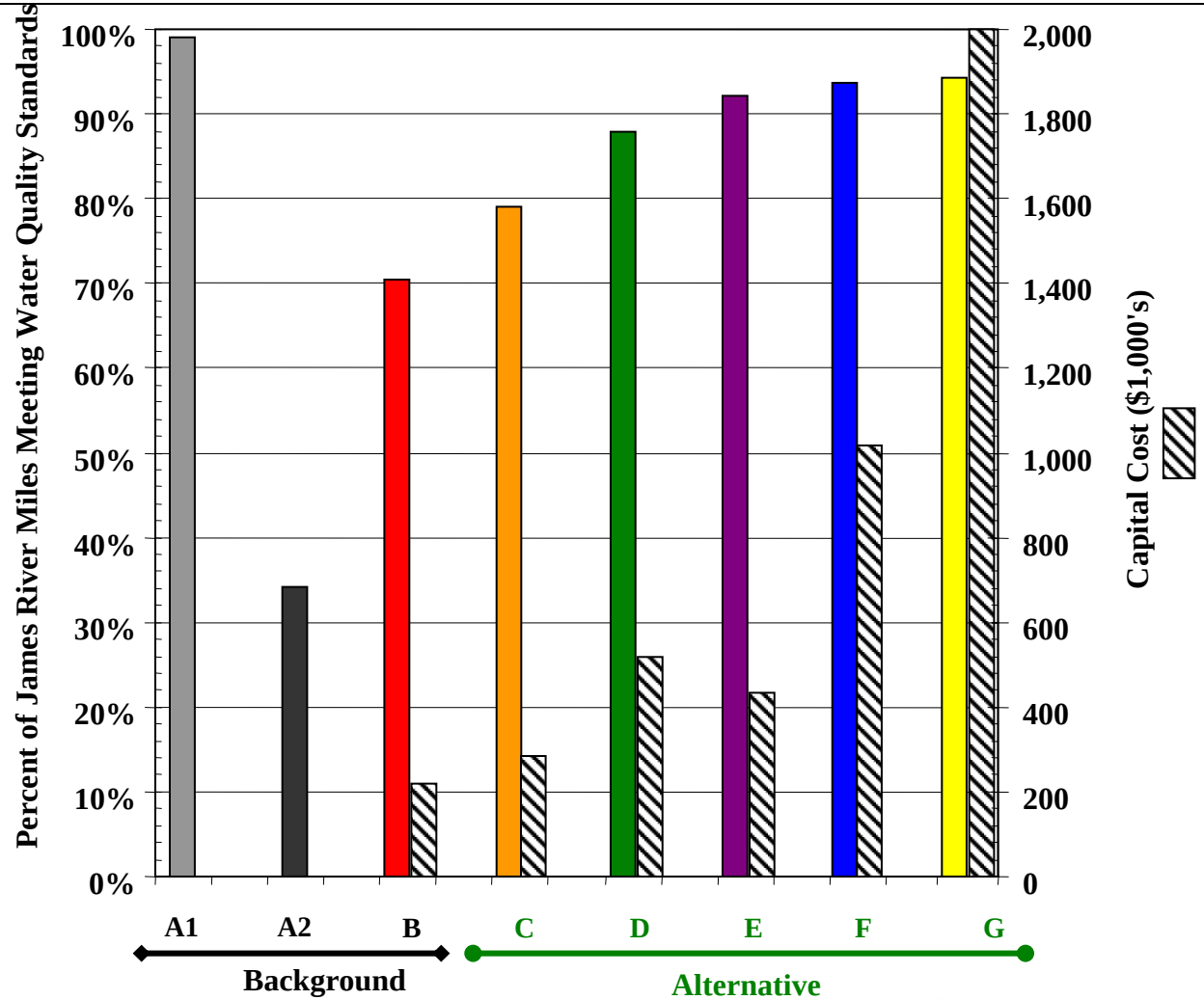
Increase CSO WWF Treatment & Shockoe Expansion With Disinfection Plus Lower Gillies Creek Conveyance



GREELEY AND HANSEN

Comparative WQ & Cost Performance of Alternatives

Note:
The bacteriological water quality standard is based on the fecal coliform 30-day geometric mean of 200 MPN per 100 mL



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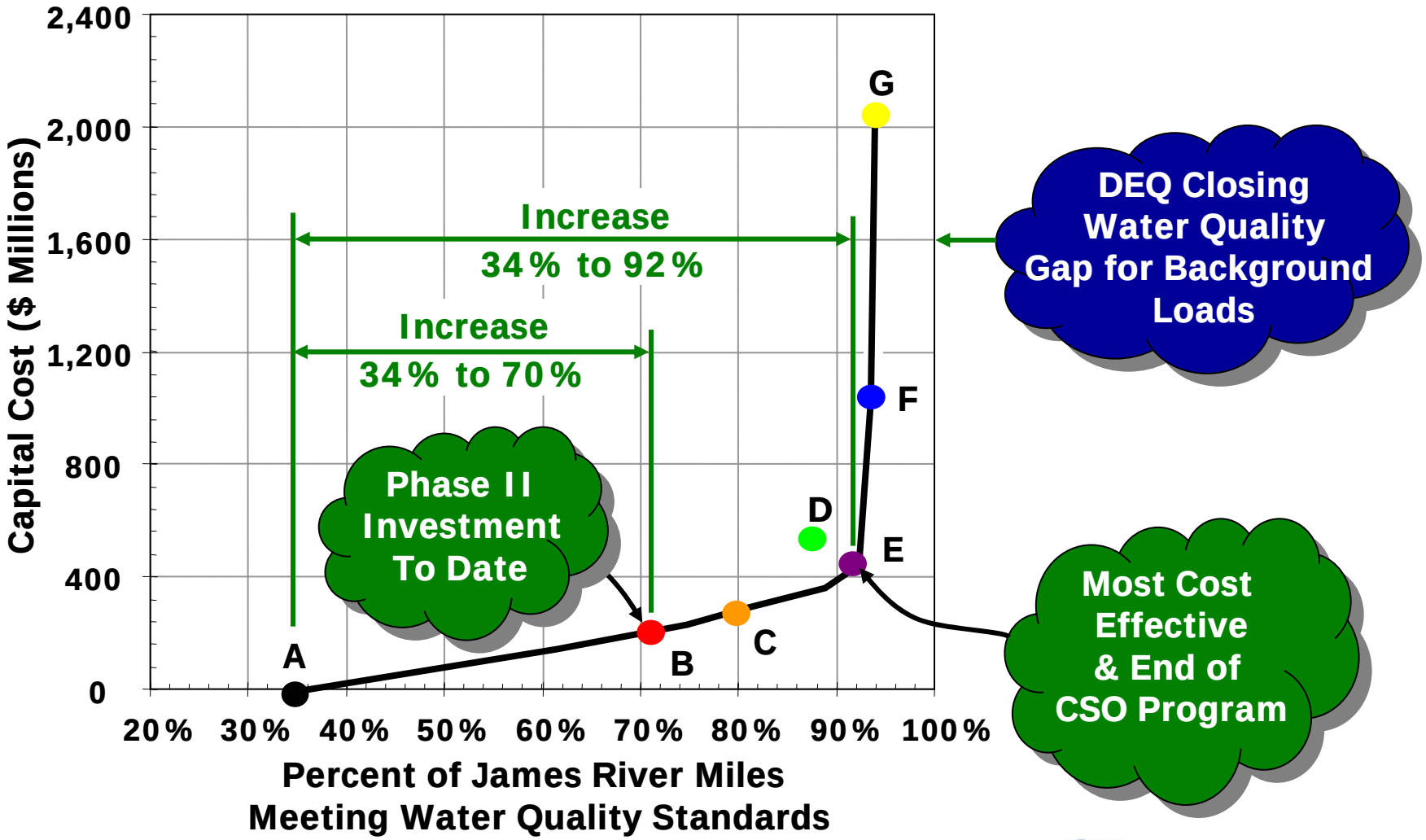
Water Quality Standards Gap

Water Quality Standards Coordination

Percent of James River Miles Meeting Fecal Coliform WQS



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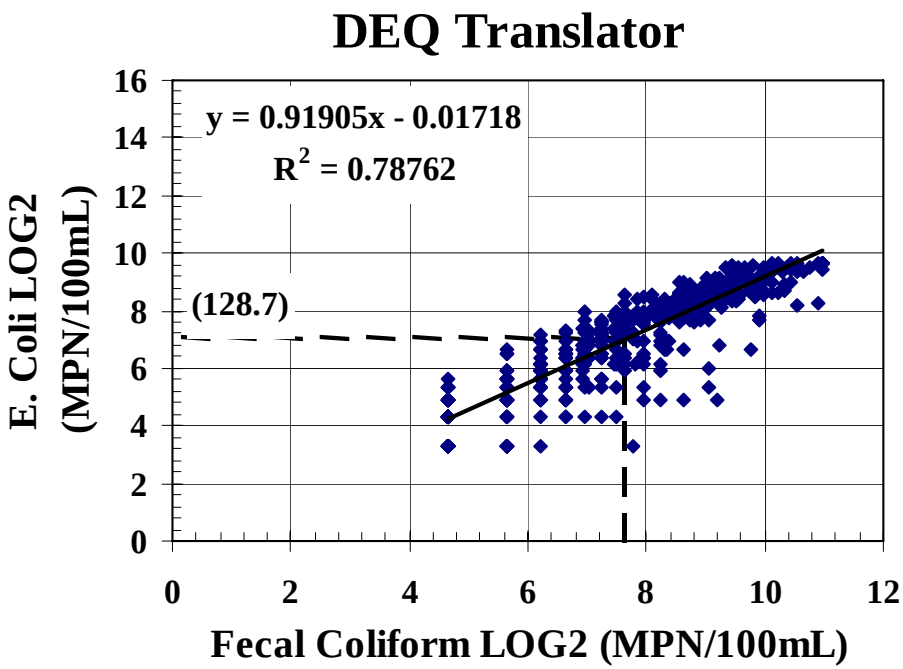
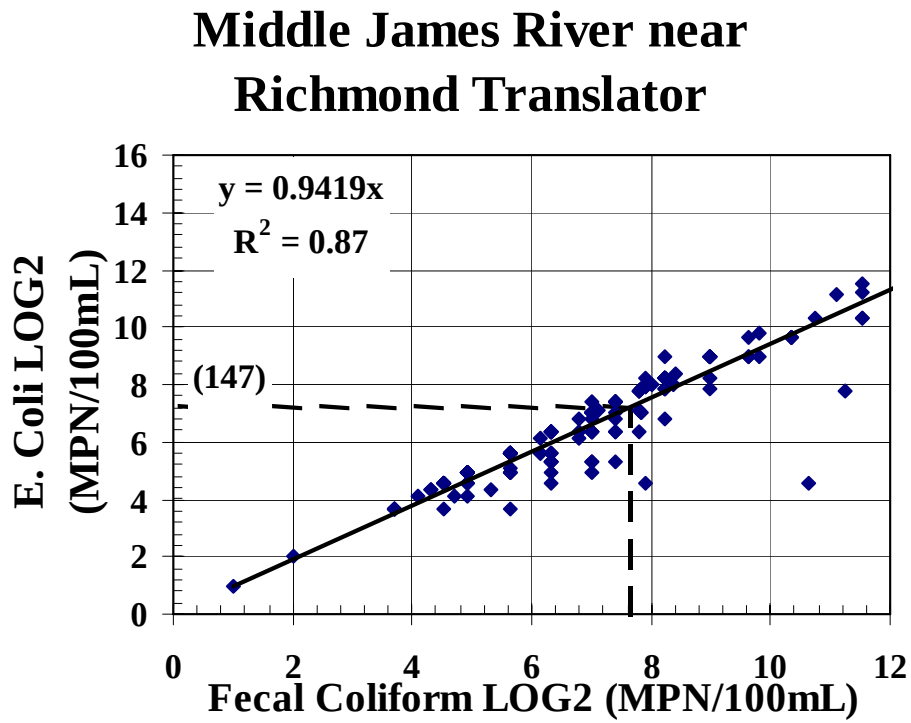
Richmond CSO Control Program

DEQ & Richmond FC to EC Translators





May Need to Re-Calculate Using DEQ Routine Monitoring Data

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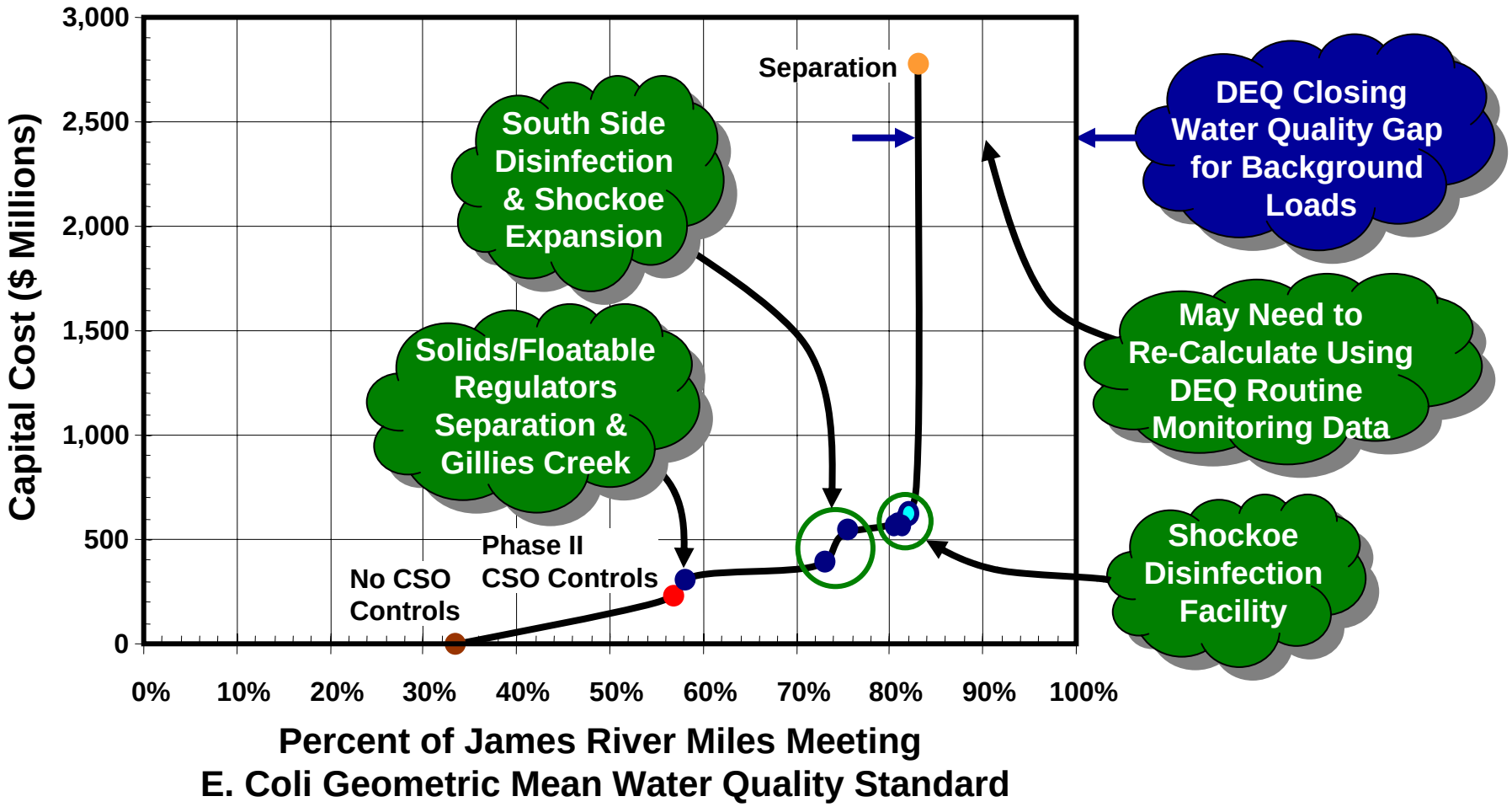
Water Quality Standards Coordination

Percent of James River Miles Meeting E-Coli WQS



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EPA Public Health Guidelines

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

History – Initial WQ Criteria

- Epidemiological Studies Conducted in 1940's & 1950's by US Public Health Service
- First Water Quality Criteria
  - Proposed by National Technical Advisory Committee (NTAC) in 1968
  - Studies show significant illnesses at total coliform of 2300 cfu/100ml
    - Fecal coliform found to be about 18% of total coliform
    - Fecal coliform levels greater than 400 cfu/100ml would show significant illnesses
  - NTAC recommended fecal coliform as indicator
    - 30-day geometric mean of 200 cfu/100ml (half of 400 cfu/100ml)
    - 10% samples in 30-days not greater than 400 cfu/100ml

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

History – Initial WQ Criteria (Continued)

- EPA Recommend This Criterion Again in 1976
- Weakness of Early Epidemiological Studies Identified
  - Questioned data behind WQS for FC 200 GM
  - Calendar Method: Lumped illnesses from clean days with those from high coliform days
  - Swimming poorly defined
    - Did not ask if participant immersed their bodies or even if they submerged their heads
  - FC indicator includes thermo-tolerant Klebseilla species, which do not indicate the presence of fecal contamination

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

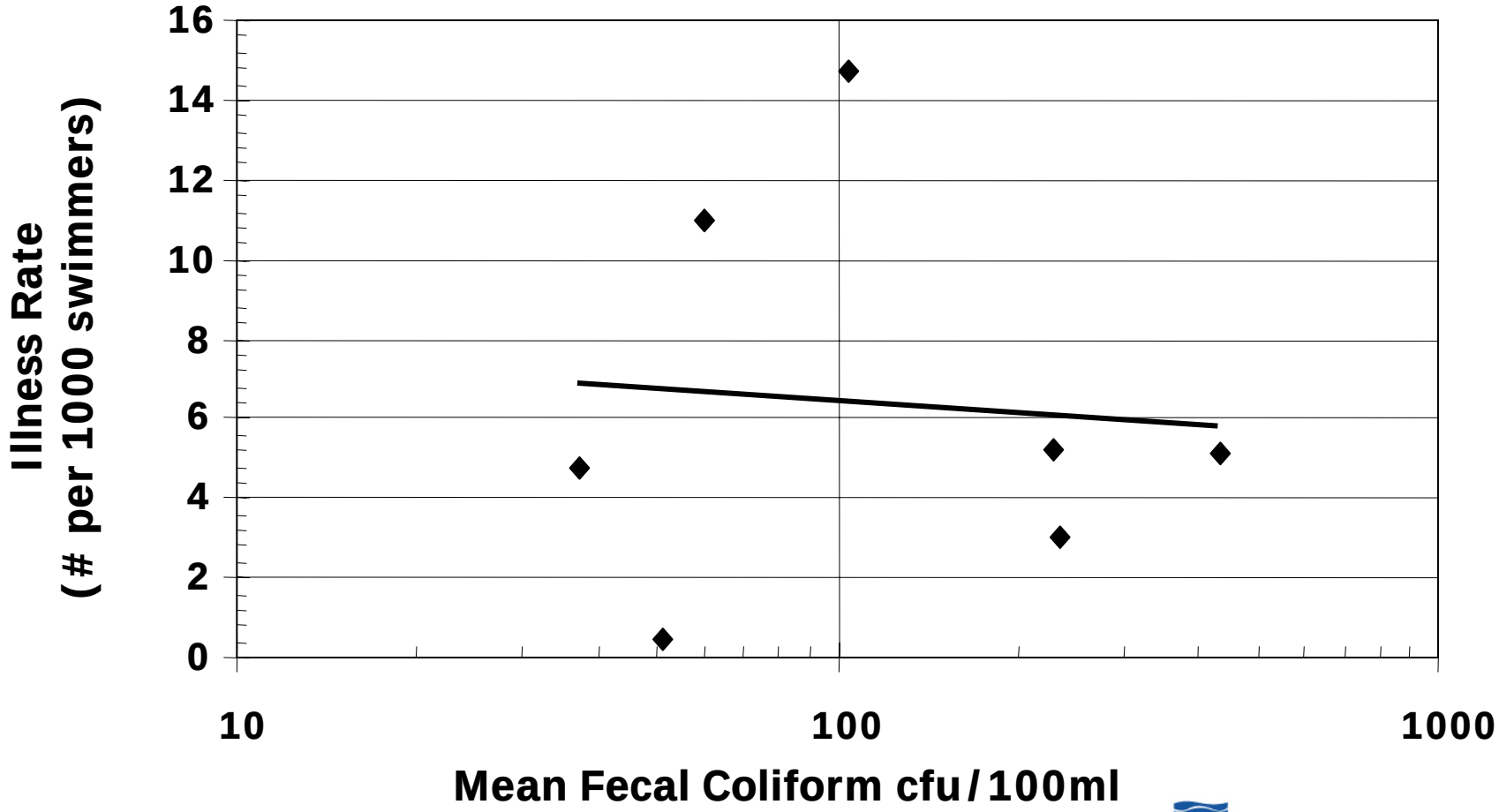
History – 1986 Guidance

- EPA Initiated Series of Studies in 1972
  - Designed to correct perceived deficiencies of earlier studies
  - Focused on fresh & marine water bathing beaches
- Epidemiological Surveys
  - Weekends only & excluded participants who swam mid-week
  - Included four general symptom categories
  - Various indicators used to determine best correlation in fresh & marine waters
  - Focused on beaches with low & high bacteria counts

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

History – 1986 Guidance *(Continued)*

Fecal Coliform Indicator in Freshwater



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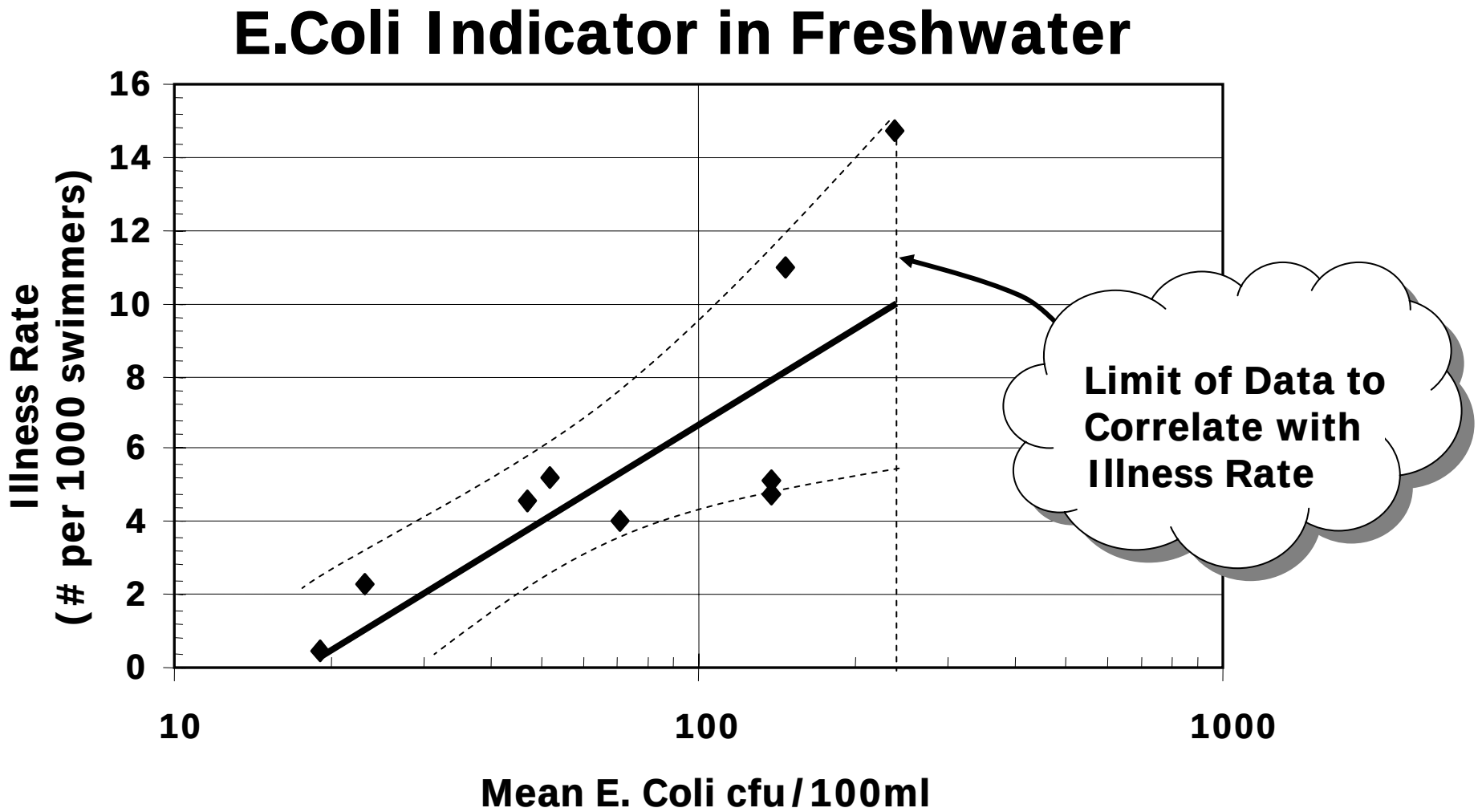
EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

History – 1986 Guidance *(Continued)*



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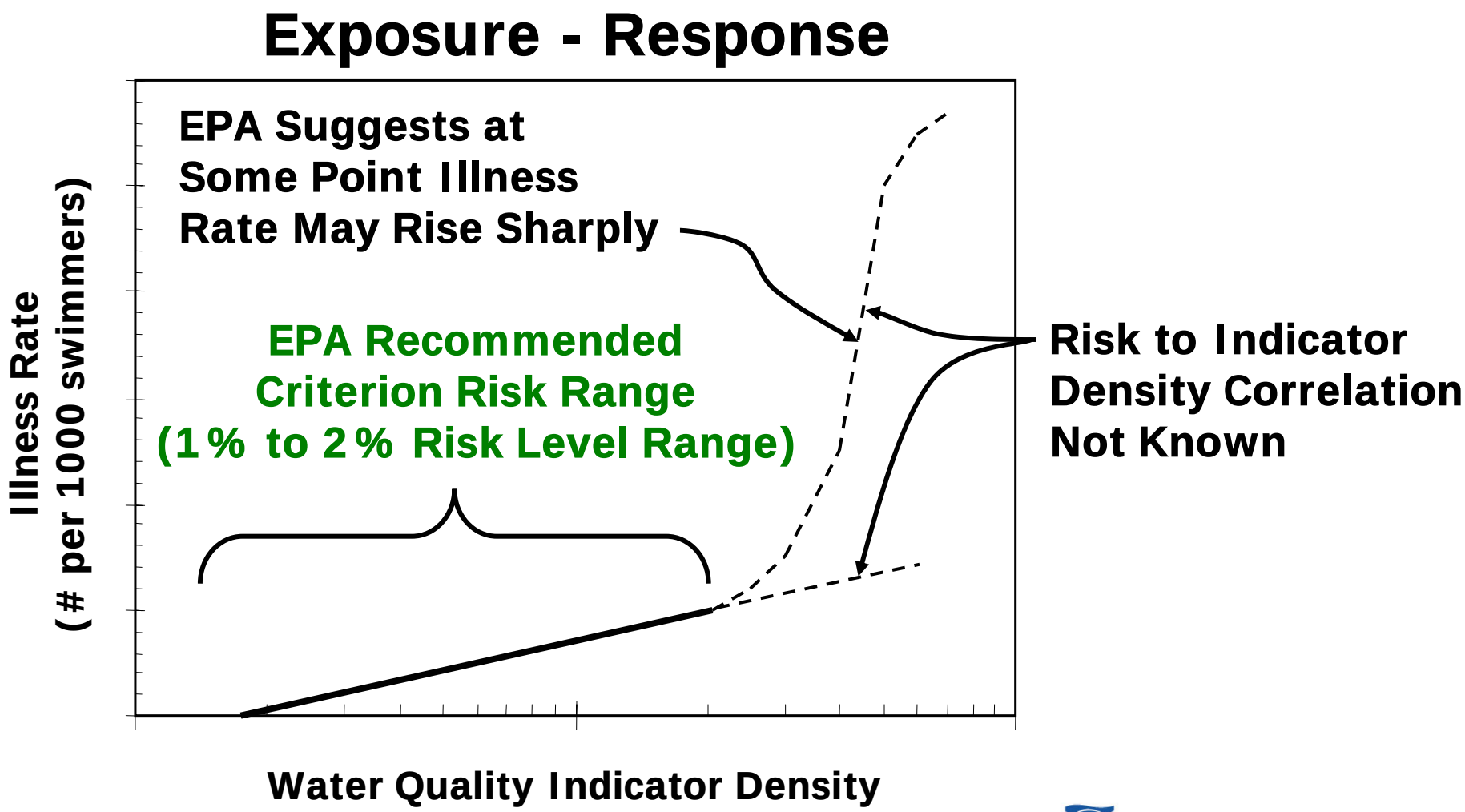
EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

November 2003 Draft Guidance



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EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

History – 1986 Guidance *(Continued)*

- EPA Recommended New Indicators (E.Coli & Enterococci)
- Established 30-Day Geometric Mean
- Established Single Sample Maximum
  - Based on Confidence Level (C.L.) & log standard deviation of 0.4 for Freshwater & 0.7 for Marine Water
  - EPA recommends that each jurisdiction establish site specific standard deviations

Indicator	Illnesses per 1,000 Swimmers	30-Day Geometric Mean	Single Sample Maximum			
			Upper 75% C.L.	Upper 82% C.L.	Upper 90% C.L.	Upper 95% C.L.
Freshwater						
Enterococci	8	33	61	78	107	151
E. Coli	8	126	235	298	410	576
Marine Water						
Enterococci	19	35	104	158	275	500

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

EPA Updating Guidance

- Three subsequent drafts
  - February 2000
  - May 2002
  - November 2003 *(Seems to have been rescinded)*
- Drafts Summarize 1986 Guidance & Provides Recommendations for Implementation of Bacteriological Criteria

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

November 2003 Draft Guidance *(Continued)*

- Historical acceptable risk levels estimated to be about 0.8% of swimmers at fresh water beaches
  - Based on ratios of fecal coliform to E. coli
  - EPA stated in 1986 Guidance regarding FC WQS
    - "While this [risk] level was based on the historically accepted risk, it is still arbitrary insofar as the historical risk was itself arbitrary."
- "EPA recommends that states and authorized tribes adopt fresh water criteria based on risk levels at or below 1.0%"

EPA's Water Quality Standards for Coastal & Great Lakes Recreation Waters
Final rule Summary

- Only applies to Great Lakes and marine coastal recreation waters (including coastal estuaries). Does not apply to inland waters. For all other waters (I.e., waters that are not coastal recreation waters), CWA and EPA implementing regulations require States to adopt criteria that are scientifically defensible and sufficient to protect the designated uses of those waters.

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Geometric Mean
and/or
Single Sample Maximum

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

November 2003 Draft Guidance *(Continued)*

- "Single Sample Maximum"
  - Never Intended to be "Value not to Exceed" Regarding Attainment Decisions
  - EPA dropping use of term for more statistically correct term "Upper Percentile Value"
  - Daily exposure statistically related to GM
- Geometric Mean Best Indicator for Long Term Water Quality Conditions (Especially Chronic Pollution)

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

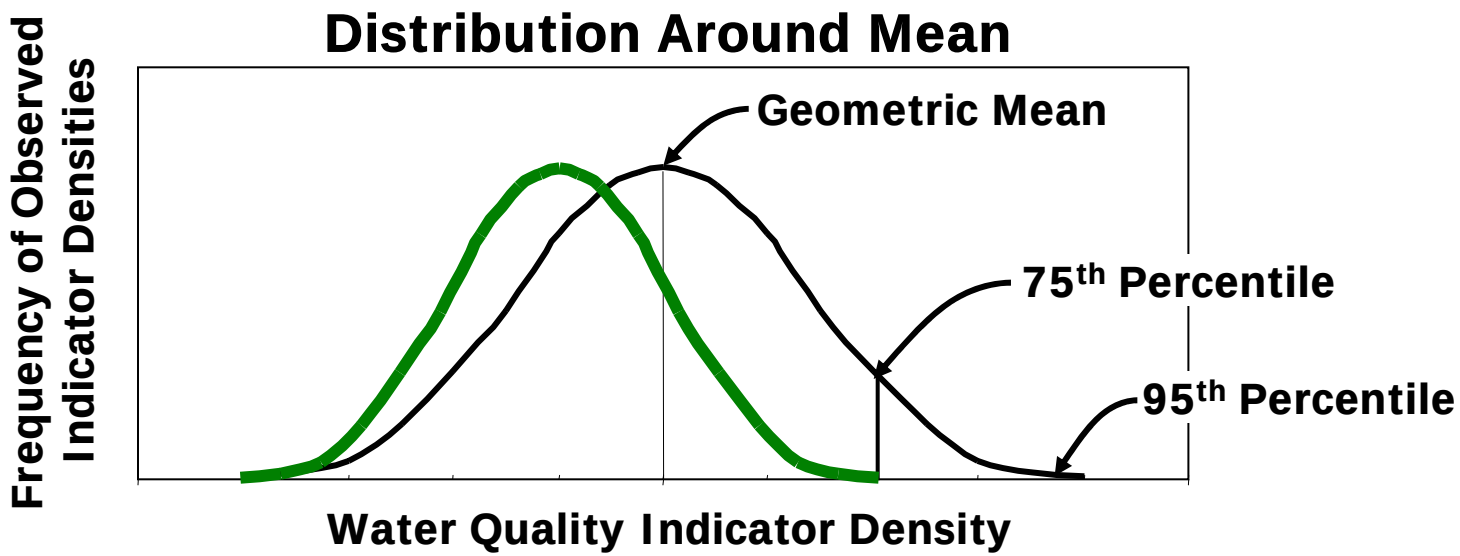
November 2003 Draft Guidance *(Continued)*

- After Adoption of EC Criteria
  - EPA recommends use of only GM component for NPDES WQBELs. States can use both GM and UPV, or the UPV expressed as a daily average limit. Underlying principle is that whichever approach is selected, the permitting authority must determine that permit limits and requirements derive from and comply with applicable WQS.

EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

November 2003 Draft Guidance *(Continued)*

- 75th Upper Percentile Value (UPV)
  - 25% of samples greater than 75th UPV
  - More values greater than UPV, higher probability of exceeding the geometric mean



EPA's Implementation Guidance for Ambient Water Quality Criteria for Bacteria

November 2003 Draft Guidance *(Continued)*

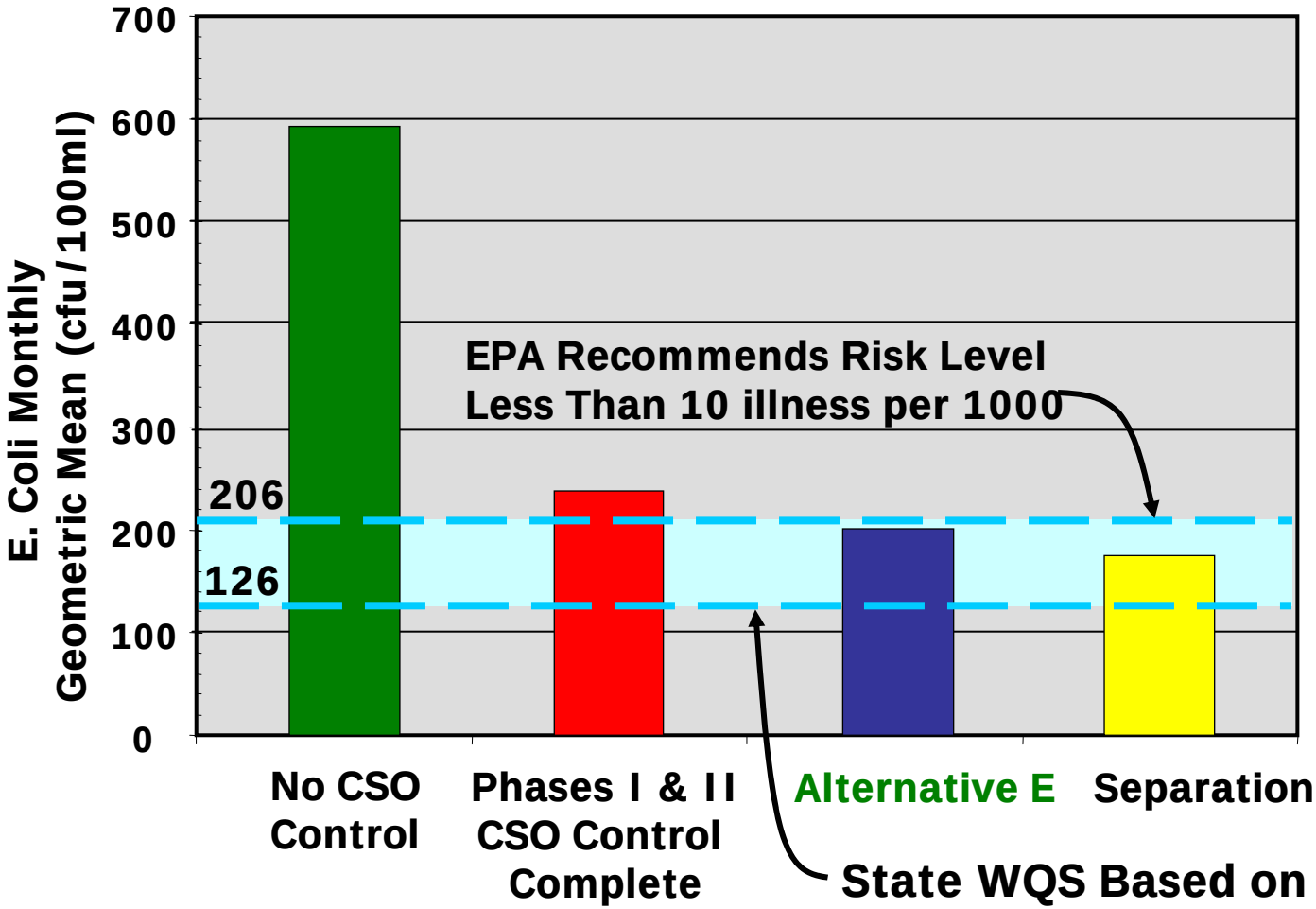
- Upper Percentile Value
  - Primary use: Beach Monitoring
  - Best predictor of today's condition would be yesterday's measurement alone & greater period between measurements, the less their predictive value (USEPA, 2003)
- Risk Management Decisions
  - Issue public warnings
  - Close the beach

2.2.1 How should the water quality criteria for bacteria be used in beach monitoring & notification programs?

EPA recommends that states and tribes use only the upper percentile value as the basis for making public notification decisions. The geometric means expressed in EPA's criteria represent a central tendency over the course of an entire swimming season (e.g., several months). As such, water quality measurements taken on any given day could be above the geometric mean and still represent protective conditions over the course of the swimming season, as long as they are balanced with measurements that fall below the geometric mean. Thus comparing an individual water quality measurement to a long term geometric mean could result in beach closures nearly half the time at a beach which has sufficiently protective conditions over the course of the entire season and where the use would ultimately not be deemed impaired.

Richmond CSO Control Program

Geometric Mean & Associated Risk Level
Maximum Month for Critical Reach



EPA's Recommended Risk Level for Fresh Water Primary Contact Recreation

1.0% of Swimmers

0.8% of Swimmers

PRELIMINARY

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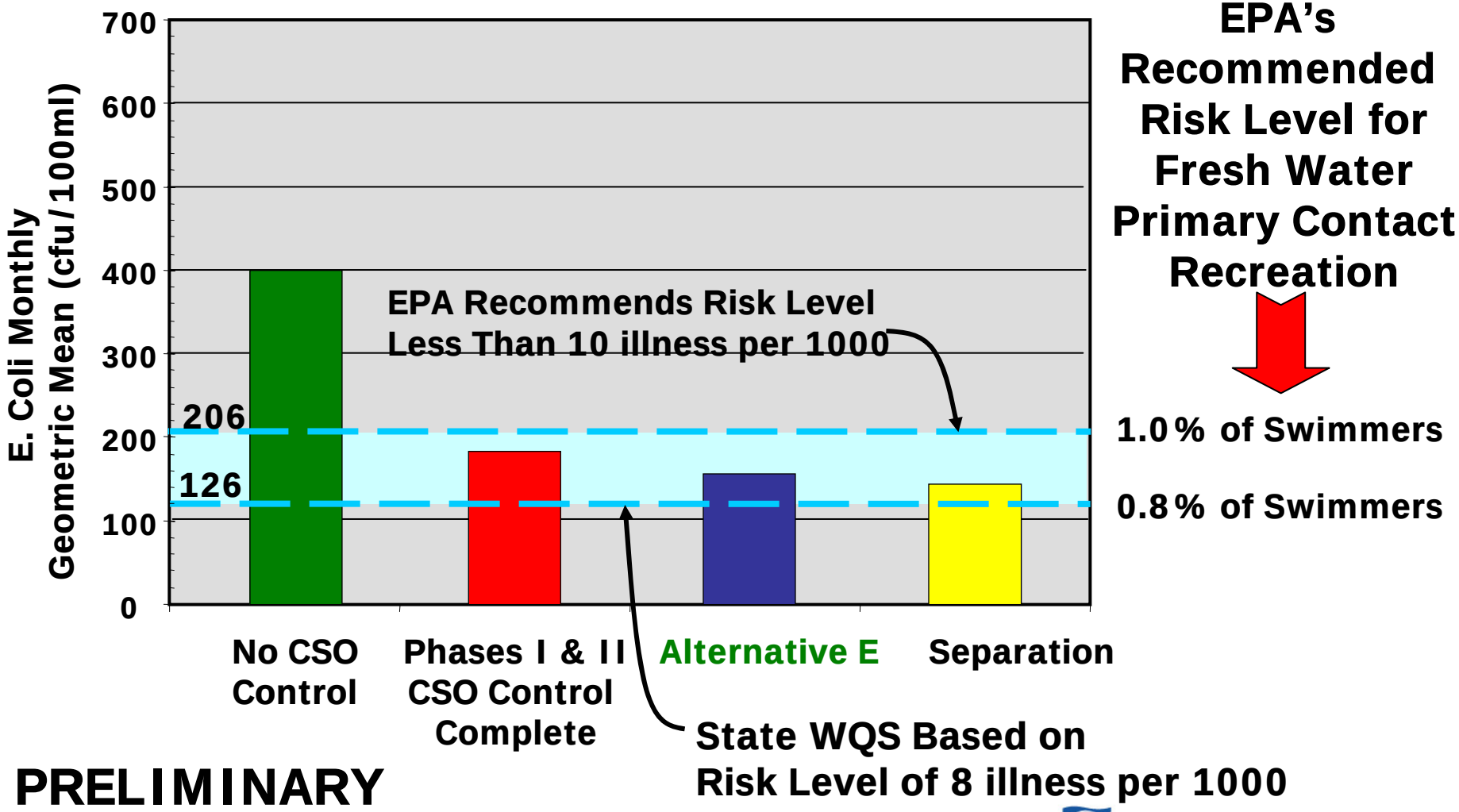
Richmond CSO Control Program

Geometric Mean & Associated Risk Level
Maximum Month for Average of River Reaches



PRELIMINARY

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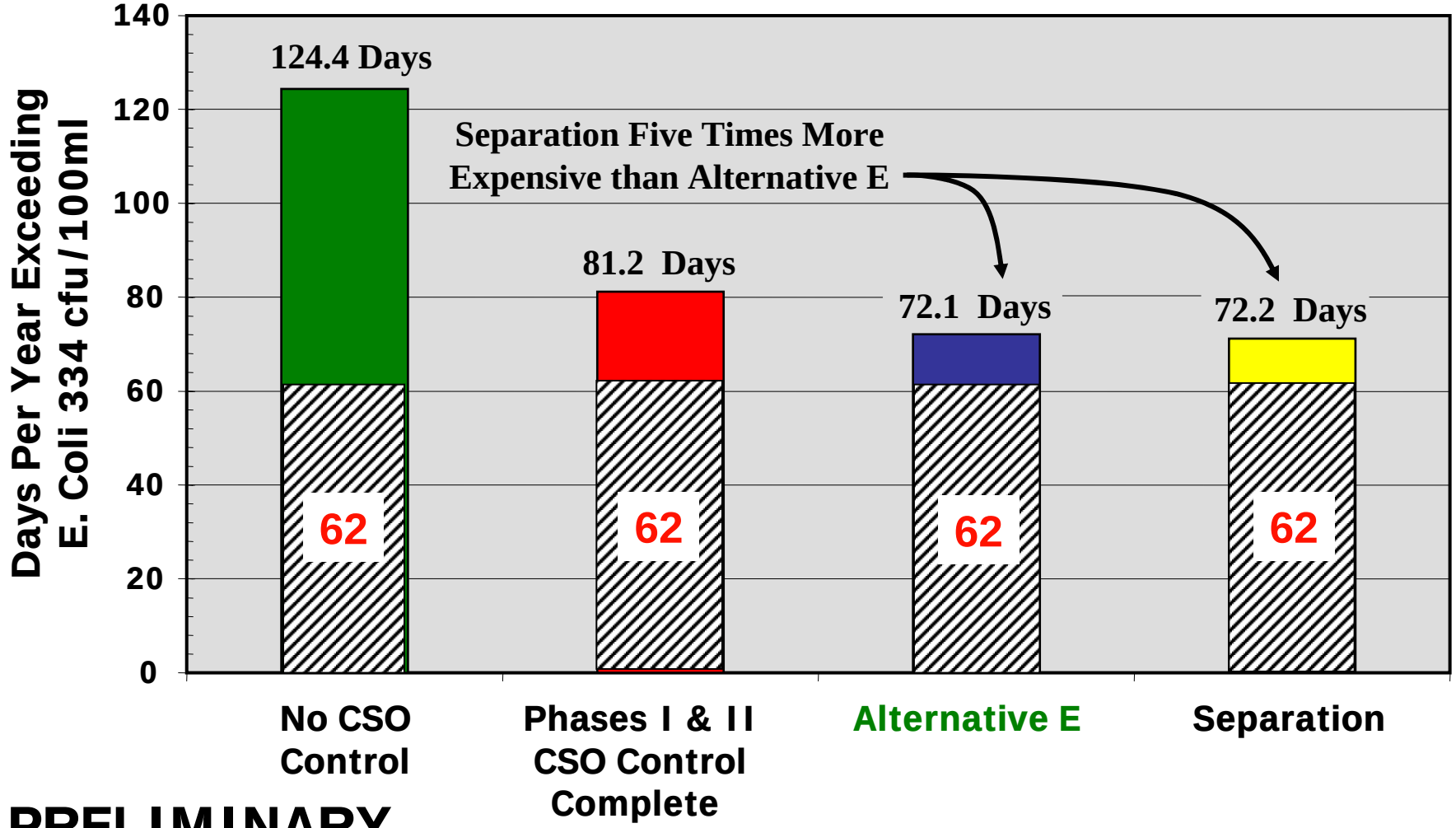
Richmond CSO Control Program

Average of River Reaches

Days Per Year Exceeding E. Coli 75th Upper Percentile Value



PRELIMINARY

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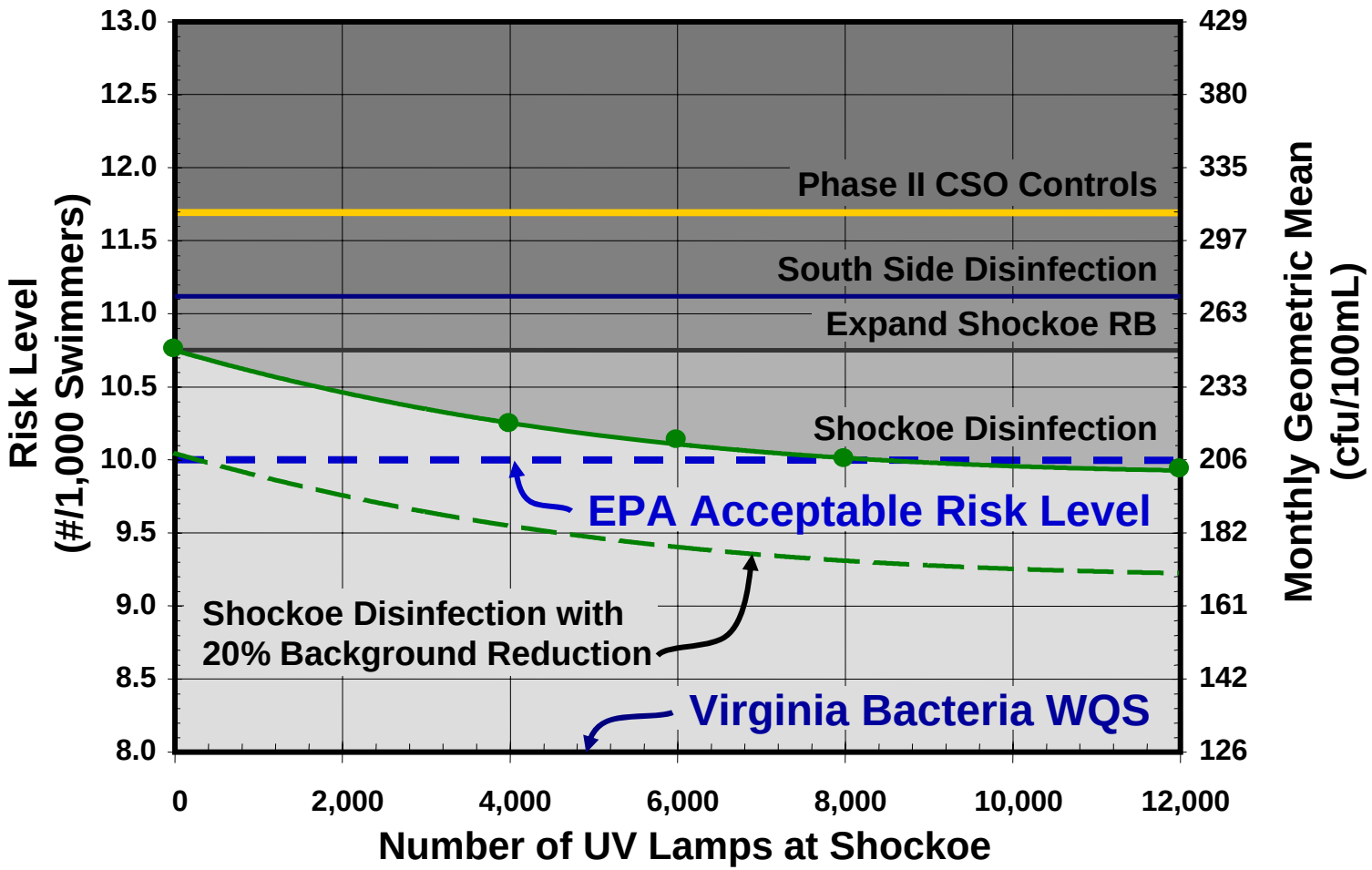
CSO Control Plan E – Bacteria Analyses E-Coli 126 MPN/100 ML Geo Mean Exceedance (Avg. Year)

River Mile	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSO Only Exceedance (All Mos)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSO +B.G. Exceedance (May)	0	E	E	E	E	E	E	E	E	E	E	E	E	E	0	0	0	0	0	0	0
(Jun)	0	0	E	E	0	0	E	E	E	E	E	E	0	0	0	0	0	0	0	0	0
(Jul)	0	0	E	0	0	0	E	E	E	E	0	0	0	0	0	0	0	0	0	0	0
(Aug)	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	0	0	0	0	0	0
CSO +20%B.G. Red. Exceedance (May)	0	0	0	0	0	0	E	E	E	0	0	0	0	0	0	0	0	0	0	0	0
(Aug)	E	E	E	E	E	E	E	E	E	E	E	E	0	0	0	0	0	0	0	0	0
CSO +25%B.G. Red. Exceedance (May)	0	0	0	0	0	0	0	E	E	0	0	0	0	0	0	0	0	0	0	0	0
(Aug)	E	E	E	E	E	E	E	E	E	E	E	0	0	0	0	0	0	0	0	0	0
CSO +40%B.G. Red. Exceedance (Aug)	0	0	E	E	0	0	0	E	E	0	0	0	0	0	0	0	0	0	0	0	0
CSO +45%B.G. Red. Exceedance (All Mos)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Shockoe UV Facility Performance: James River Reach 13 for August



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Water Quality Model Results In Terms of:

> E. coli

> Illness Rate Per 1000 Swimmers

Water Quality Modeling Results – Alt A1: "No City"

E-Coli - Monthly Geometric Mean (#/100ml)																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	43	47	51	52	51	53	61	68	70	69	68	67	66	63	61	58	56	54	52	51
	Feb	47	49	50	50	48	49	53	56	57	56	55	55	54	53	52	51	50	48	47	46
	Mar	46	49	52	52	51	52	59	65	66	65	64	63	63	63	61	60	58	57	56	55
	April	76	79	81	80	78	78	84	88	89	87	85	84	83	81	79	78	76	74	73	71
	May	107	114	120	121	119	122	**134**	**147**	**150**	**147**	**143**	**138**	**134**	**127**	120	113	107	101	96	93
	June	99	103	108	108	105	107	116	125	**127**	124	119	113	109	104	97	92	86	81	78	75
	Jul	69	77	84	84	82	86	101	114	115	108	100	92	86	78	70	63	57	52	49	47
	Aug	84	93	100	101	98	104	119	**134**	**137**	**131**	123	114	108	100	91	83	76	71	67	64
	Sept	52	57	61	61	59	62	72	81	81	76	71	66	62	57	52	48	44	42	40	39
	Oct	56	61	66	65	63	65	74	82	81	76	71	65	62	57	51	47	43	40	39	39
	Nov	65	70	73	72	69	71	78	85	85	80	74	68	64	59	54	50	45	43	41	39
	Dec	53	59	65	66	65	68	78	88	91	90	89	88	88	86	82	78	75	71	68	66

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	3.6	4.0	4.3	4.4	4.3	4.5	5.0	5.5	5.6	5.5	5.5	5.4	5.3	5.2	5.0	4.8	4.7	4.5	4.4	4.3
	Feb	4.0	4.1	4.2	4.2	4.1	4.2	4.5	4.7	4.8	4.7	4.7	4.6	4.6	4.5	4.4	4.3	4.2	4.1	4.0	3.9
	Mar	3.9	4.2	4.4	4.4	4.3	4.4	4.9	5.3	5.4	5.3	5.2	5.2	5.2	5.1	5.0	5.0	4.9	4.8	4.7	4.6
	April	5.9	6.1	6.2	6.2	6.0	6.1	6.3	6.6	6.6	6.5	6.4	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.8	5.7
	May	7.3	7.6	7.8	7.8	7.8	7.9	**8.3**	**8.6**	**8.7**	**8.6**	**8.5**	**8.4**	**8.2**	**8.0**	7.8	7.6	7.3	7.1	6.9	6.7
	June	7.0	7.2	7.4	7.4	7.3	7.3	7.7	8.0	**8.0**	7.9	7.8	7.6	7.4	7.2	7.0	6.7	6.5	6.2	6.0	5.9
	Jul	5.6	6.0	6.3	6.4	6.2	6.5	7.1	7.6	7.6	7.4	7.1	6.7	6.4	6.1	5.6	5.2	4.8	4.4	4.2	4.0
	Aug	6.4	6.8	7.1	7.1	7.0	7.2	7.8	**8.3**	**8.3**	**8.2**	7.9	7.6	7.4	7.1	6.7	6.3	6.0	5.7	5.4	5.2
	Sept	4.4	4.8	5.0	5.0	4.9	5.1	5.7	6.2	6.2	5.9	5.6	5.4	5.1	4.8	4.4	4.1	3.7	3.5	3.3	3.2
	Oct	4.7	5.0	5.3	5.3	5.2	5.3	5.8	6.2	6.2	6.0	5.6	5.3	5.1	4.8	4.3	4.0	3.6	3.4	3.2	3.2
	Nov	5.3	5.6	5.8	5.7	5.6	5.6	6.1	6.4	6.4	6.1	5.8	5.5	5.2	4.9	4.6	4.2	3.8	3.6	3.4	3.2
	Dec	4.5	4.9	5.3	5.4	5.3	5.5	6.1	6.6	6.7	6.6	6.6	6.5	6.5	6.4	6.3	6.1	5.9	5.7	5.5	5.3

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Water Quality Modeling Results – Alt A2: "No CSO Control"

E-Coli - Monthly Geometric Mean (#/100ml)																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	106	122	126	124	121	120	127	133	133	130	128	126	125	122	119	116	113	109	107	104
	Feb	80	89	93	94	93	94	100	105	105	102	101	99	97	95	92	90	88	86	84	82
	Mar	93	107	112	113	112	117	129	138	141	138	137	135	134	131	127	124	120	116	113	110
	April	114	122	125	124	123	123	128	133	132	130	128	126	124	121	118	116	113	109	107	105
	May	229	261	274	273	267	265	274	283	279	266	252	238	225	211	198	185	173	163	154	146
	June	181	203	214	215	211	213	226	239	239	232	223	213	206	196	186	177	168	160	154	148
	Jul	315	352	356	342	323	310	312	315	302	281	260	241	225	208	190	175	162	150	141	132
	Aug	499	572	593	575	543	517	507	498	470	430	393	359	332	304	279	257	238	223	210	199
	Sept	217	249	257	248	238	238	250	260	254	236	220	206	195	181	165	150	137	128	121	114
	Oct	165	180	179	169	157	150	153	157	151	140	129	120	113	106	97	90	83	77	74	71
	Nov	255	274	264	244	221	204	195	188	174	157	142	129	117	107	98	89	81	75	70	66
	Dec	158	190	207	214	215	220	235	249	251	246	242	237	234	228	220	211	201	192	183	174

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	7.3	7.9	8.0	8.0	7.8	7.8	8.0	8.2	8.2	8.1	8.1	8.0	8.0	7.9	7.8	7.7	7.6	7.4	7.3	7.2
	Feb	6.1	6.6	6.8	6.8	6.8	6.8	7.1	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2
	Mar	6.8	7.3	7.5	7.5	7.5	7.7	8.1	8.4	8.5	8.4	8.3	8.3	8.3	8.2	8.0	7.9	7.8	7.7	7.6	7.4
	April	7.6	7.9	8.0	8.0	7.9	7.9	8.1	8.2	8.2	8.1	8.1	8.0	7.9	7.8	7.7	7.7	7.6	7.4	7.4	7.3
	May	10.5	11.0	11.2	11.2	11.1	11.0	11.2	11.3	11.2	11.0	10.8	10.6	10.4	10.1	9.8	9.6	9.3	9.1	8.8	8.6
	June	9.5	10.0	10.2	10.2	10.1	10.1	10.4	10.6	10.6	10.5	10.3	10.2	10.0	9.8	9.6	9.4	9.2	9.0	8.8	8.7
	Jul	11.7	12.2	12.2	12.1	11.8	11.7	11.7	11.7	11.6	11.3	11.0	10.7	10.4	10.1	9.7	9.3	9.0	8.7	8.5	8.2
	Aug	13.6	14.2	14.3	14.2	14.0	13.8	13.7	13.6	13.4	13.0	12.6	12.3	12.0	11.6	11.2	10.9	10.6	10.3	10.1	9.9
	Sept	10.2	10.8	10.9	10.8	10.6	10.6	10.8	11.0	10.9	10.6	10.3	10.0	9.8	9.5	9.1	8.7	8.3	8.1	7.8	7.6
	Oct	9.1	9.5	9.4	9.2	8.9	8.7	8.8	8.9	8.7	8.4	8.1	7.8	7.6	7.3	6.9	6.6	6.3	6.0	5.8	5.6
	Nov	10.9	11.2	11.0	10.7	10.3	10.0	9.8	9.6	9.3	8.9	8.5	8.1	7.7	7.3	7.0	6.6	6.2	5.9	5.6	5.4
	Dec	8.9	9.7	10.0	10.2	10.2	10.3	10.6	10.8	10.8	10.7	10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.7	9.5	9.3

GREELEY AND HANSEN

Water Quality Modeling Results – Alt B: Phase II Controls

E-Coli - Monthly Geometric Mean (#/100ml)																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	80	90	93	91	88	87	93	99	100	97	95	93	92	89	86	83	80	77	75	73
	Feb	62	67	69	69	67	67	71	75	75	73	71	70	69	67	65	63	61	59	57	55
	Mar	74	84	87	86	84	87	97	104	106	103	100	98	97	94	90	88	85	82	80	77
	April	99	104	106	105	103	102	106	110	110	107	105	103	102	99	97	94	92	90	88	87
	May	**152**	**168**	**177**	**177**	**172**	**173**	**185**	**196**	**197**	**189**	**181**	**173**	**164**	**154**	**144**	**135**	**127**	119	113	108
	June	**140**	**154**	**161**	**161**	**156**	**157**	**168**	**179**	**180**	**174**	**166**	**159**	**153**	**146**	**137**	**130**	123	116	111	107
	Jul	**181**	**200**	**203**	**196**	**185**	**183**	**194**	**203**	**199**	**186**	**174**	**162**	**152**	**141**	**130**	119	111	104	99	93
	Aug	**280**	**318**	**332**	**323**	**304**	**295**	**303**	**310**	**301**	**279**	**256**	**236**	**220**	**203**	**186**	**172**	**159**	**150**	**143**	**137**
	Sept	123	**137**	**141**	**135**	**129**	**131**	**145**	**157**	**157**	**148**	**138**	**131**	125	117	107	99	91	87	83	81
	Oct	123	**134**	**136**	**129**	120	116	121	**127**	123	116	107	100	95	88	81	74	69	64	61	59
	Nov	**136**	**145**	**142**	**132**	120	113	115	118	113	103	94	85	78	71	65	59	54	51	48	46
	Dec	113	**135**	**146**	**149**	**148**	**150**	**163**	**175**	**176**	**173**	**169**	**165**	**163**	**158**	**152**	**145**	**138**	**131**	125	119

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	6.2	6.6	6.8	6.7	6.5	6.5	6.8	7.0	7.1	6.9	6.9	6.8	6.7	6.6	6.5	6.3	6.2	6.0	5.9	5.8
	Feb	5.1	5.4	5.6	5.5	5.4	5.5	5.7	5.9	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	4.9	4.8	4.7
	Mar	5.8	6.3	6.5	6.4	6.4	6.5	6.9	7.2	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.5	6.4	6.2	6.1	6.0
	April	7.0	7.2	7.3	7.3	7.2	7.2	7.3	7.5	7.5	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.6	6.5
	May	**8.8**	**9.2**	**9.4**	**9.4**	**9.3**	**9.3**	**9.6**	**9.8**	**9.8**	**9.7**	**9.5**	**9.3**	**9.1**	**8.8**	**8.6**	**8.3**	**8.0**	7.8	7.6	7.4
	June	**8.4**	**8.8**	**9.0**	**9.0**	**8.9**	**8.9**	**9.2**	**9.4**	**9.5**	**9.3**	**9.1**	**9.0**	**8.8**	**8.6**	**8.4**	**8.1**	7.9	7.7	7.5	7.3
	Jul	**9.5**	**9.9**	**10.0**	**9.8**	**9.6**	**9.5**	**9.8**	**10.0**	**9.9**	**9.6**	**9.3**	**9.0**	**8.8**	**8.5**	**8.1**	7.8	7.5	7.2	7.0	6.8
	Aug	**11.3**	**11.8**	**12.0**	**11.8**	**11.6**	**11.5**	**11.6**	**11.7**	**11.6**	**11.3**	**10.9**	**10.6**	**10.3**	**10.0**	**9.6**	**9.3**	**9.0**	**8.7**	**8.5**	**8.3**
	Sept	7.9	**8.4**	**8.5**	**8.3**	**8.1**	**8.2**	**8.6**	**8.9**	**8.9**	**8.7**	**8.4**	**8.2**	8.0	7.7	7.4	7.0	6.7	6.5	6.3	6.2
	Oct	7.9	**8.3**	**8.3**	**8.1**	7.8	7.7	7.9	**8.0**	7.9	7.7	7.3	7.1	6.8	6.5	6.2	5.9	5.5	5.2	5.1	4.9
	Nov	**8.3**	**8.6**	**8.5**	**8.2**	7.8	7.6	7.6	7.7	7.5	7.2	6.8	6.4	6.0	5.7	5.3	4.9	4.6	4.3	4.1	3.9
	Dec	7.6	**8.3**	**8.6**	**8.7**	**8.7**	**8.7**	**9.0**	**9.3**	**9.4**	**9.3**	**9.2**	**9.1**	**9.1**	**8.9**	**8.8**	**8.6**	**8.4**	**8.2**	8.0	7.8

GREELEY AND HANSEN

Water Quality Model Output: Alt E: 80% Disinfection at Shockoe

E-Coli - Monthly Geometric Mean (#/100ml)																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	56	66	69	68	66	66	73	79	80	78	77	75	73	71	68	65	63	60	58	57
	Feb	53	58	60	59	58	58	62	65	65	63	62	61	60	59	57	55	53	52	50	48
	Mar	56	64	67	66	64	66	74	80	82	80	78	77	76	74	72	69	67	65	63	62
	April	87	91	93	92	89	89	93	98	98	95	94	92	91	89	87	85	83	80	79	77
	May	124	**137**	**145**	**145**	**142**	**143**	**155**	**167**	**168**	**162**	**156**	**149**	**142**	**134**	125	117	110	104	99	95
	June	113	123	**129**	**128**	125	126	**135**	**145**	**146**	**141**	**135**	**129**	124	118	111	106	100	94	90	87
	Jul	112	124	**130**	126	118	119	**131**	**142**	**141**	**132**	122	113	105	97	87	79	73	67	64	61
	Aug	**160**	**182**	**193**	**189**	**178**	**177**	**189**	**201**	**199**	**188**	**174**	**161**	**151**	**140**	**129**	118	109	102	97	92
	Sept	74	83	87	84	80	83	94	104	105	98	92	87	84	78	72	66	61	59	57	55
	Oct	80	89	92	89	82	81	87	94	92	87	81	75	72	66	60	55	51	48	46	45
	Nov	83	91	94	89	82	81	87	92	91	84	78	72	67	62	57	52	48	45	43	42
	Dec	72	86	95	96	94	96	106	115	117	114	111	108	106	102	97	92	87	82	78	75

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	4.7	5.3	5.6	5.5	5.4	5.4	5.8	6.1	6.2	6.1	6.0	5.9	5.8	5.7	5.5	5.3	5.1	5.0	4.8	4.7
	Feb	4.5	4.8	5.0	4.9	4.8	4.9	5.1	5.3	5.3	5.2	5.1	5.1	5.0	4.9	4.8	4.6	4.5	4.4	4.2	4.1
	Mar	4.7	5.2	5.4	5.4	5.3	5.4	5.8	6.2	6.2	6.1	6.0	6.0	5.9	5.8	5.7	5.6	5.4	5.3	5.2	5.1
	April	6.5	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0
	May	7.9	**8.3**	**8.6**	**8.6**	**8.5**	**8.5**	**8.9**	**9.2**	**9.2**	**9.0**	**8.9**	**8.7**	**8.5**	**8.3**	8.0	7.7	7.5	7.2	7.0	6.8
	June	7.6	7.9	**8.1**	**8.1**	8.0	8.0	**8.3**	**8.6**	**8.6**	**8.5**	**8.3**	**8.1**	7.9	7.7	7.5	7.3	7.0	6.8	6.7	6.5
	Jul	7.5	8.0	**8.1**	8.0	7.7	7.8	**8.2**	**8.5**	**8.5**	**8.2**	7.9	7.6	7.3	6.9	6.5	6.1	5.8	5.4	5.2	5.0
	Aug	**9.0**	**9.5**	**9.8**	**9.7**	**9.4**	**9.4**	**9.7**	**9.9**	**9.9**	**9.6**	**9.3**	**9.0**	**8.8**	**8.4**	**8.1**	7.7	7.4	7.2	6.9	6.7
	Sept	5.8	6.3	6.5	6.3	6.1	6.3	6.8	7.2	7.2	7.0	6.7	6.5	6.3	6.0	5.7	5.4	5.1	4.9	4.8	4.6
	Oct	6.2	6.6	6.7	6.6	6.3	6.2	6.5	6.8	6.7	6.5	6.2	5.9	5.7	5.4	5.0	4.7	4.3	4.1	3.9	3.8
	Nov	6.3	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.1	3.8	3.6	3.5
	Dec	5.7	6.4	6.8	6.9	6.8	6.9	7.3	7.6	7.7	7.6	7.5	7.4	7.3	7.2	7.0	6.7	6.5	6.3	6.1	5.9

Water Quality Modeling Results – Alt G: Complete City-wide Separation

E-Coli - Monthly Geometric Mean (#/100ml)																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	59	64	67	67	66	67	75	82	83	81	79	77	74	71	68	64	61	59	57	55
	Feb	55	57	59	58	57	58	61	65	65	63	63	62	61	59	58	56	54	53	51	49
	Mar	59	63	65	65	63	64	71	77	78	76	74	73	72	71	69	67	65	63	62	60
	April	89	92	93	92	89	89	94	99	99	96	95	93	91	88	85	83	80	77	76	74
	May	**140**	**151**	**157**	**157**	**154**	**155**	**165**	**176**	**176**	**169**	**163**	**156**	**150**	**141**	**132**	124	116	108	103	98
	June	**126**	**134**	**137**	**135**	**131**	**130**	**138**	**146**	**146**	**140**	**134**	**127**	122	115	108	102	96	90	86	82
	Jul	109	119	123	119	112	112	124	**135**	**132**	122	112	103	95	86	77	69	63	58	54	51
	Aug	**129**	**138**	**141**	**136**	**127**	**127**	**140**	**152**	**153**	**146**	**137**	**128**	121	113	104	95	88	83	79	76
	Sept	82	88	89	85	80	81	90	98	96	88	81	74	70	64	58	53	49	46	43	41
	Oct	84	90	92	89	83	83	92	98	96	90	83	77	73	67	60	55	50	47	45	44
	Nov	89	93	94	90	84	83	89	95	93	87	81	75	70	64	59	53	49	45	43	41
	Dec	78	86	91	93	91	94	105	114	116	113	110	106	104	100	95	89	84	79	74	71

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8
Avg 74-78	Jan	4.9	5.3	5.4	5.4	5.3	5.4	5.9	6.2	6.3	6.2	6.1	6.0	5.9	5.7	5.5	5.3	5.1	4.9	4.7	4.6
	Feb	4.6	4.8	4.9	4.8	4.8	4.8	5.1	5.3	5.3	5.2	5.1	5.1	5.0	4.9	4.8	4.7	4.6	4.4	4.3	4.2
	Mar	4.9	5.2	5.3	5.3	5.2	5.3	5.7	6.0	6.0	5.9	5.8	5.8	5.7	5.7	5.5	5.4	5.3	5.2	5.1	5.0
	April	6.6	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.5	6.4	6.3	6.2	6.0	5.9	5.8
	May	**8.4**	**8.7**	**8.9**	**8.9**	**8.8**	**8.8**	**9.1**	**9.4**	**9.4**	**9.2**	**9.1**	**8.9**	**8.7**	**8.5**	**8.2**	7.9	7.7	7.4	7.2	7.0
	June	**8.0**	**8.3**	**8.4**	**8.3**	**8.2**	**8.1**	**8.4**	**8.6**	**8.6**	**8.4**	**8.2**	**8.0**	7.9	7.6	7.4	7.1	6.9	6.6	6.4	6.3
	Jul	7.4	7.8	7.9	7.8	7.5	7.5	8.0	**8.3**	**8.2**	7.9	7.5	7.2	6.8	6.5	6.0	5.6	5.1	4.8	4.6	4.3
	Aug	**8.1**	**8.4**	**8.5**	**8.3**	**8.1**	**8.1**	**8.4**	**8.8**	**8.8**	**8.6**	**8.3**	**8.1**	7.9	7.6	7.2	6.9	6.5	6.3	6.1	5.9
	Sept	6.3	6.5	6.6	6.4	6.2	6.2	6.7	7.0	6.9	6.6	6.2	5.9	5.6	5.2	4.8	4.5	4.1	3.9	3.7	3.5
	Oct	6.4	6.6	6.7	6.6	6.3	6.3	6.7	7.0	6.9	6.6	6.3	6.0	5.8	5.4	5.0	4.6	4.3	4.0	3.8	3.7
	Nov	6.6	6.8	6.8	6.6	6.3	6.3	6.6	6.8	6.8	6.5	6.2	5.9	5.6	5.3	4.9	4.5	4.1	3.8	3.6	3.4
	Dec	6.0	6.5	6.7	6.7	6.7	6.8	7.2	7.6	7.7	7.6	7.4	7.3	7.2	7.1	6.8	6.6	6.3	6.1	5.9	5.6

City of Richmond

GREELEY AND HANSEN

Path Forward

Proposed CSO LTCP Path Forward

- Technical plan
- WQS (Demonstration Approach)
- DEQ TMDL

City of Richmond

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DEQ's TMDL for Bacteria

DEQ James River Bacteria TMDL

- Content & Schedule
- Potential Outcomes Scenarios
- EPA Watershed Approach?

City of Richmond

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Discussion